TREATMENT OF PATELLOFEMORAL INSTABILITY

COLOFON

Cover/layout: Dagmar Wynants, Studio KEET
Production: BoekenGilde, Enschede

ISBN: 978-90-9032222-3

FINANCIAL SUPPORT
Nederlandse Orthopaedische Vereniging (NOV)
Radboud University
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TREATMENT OF PATELLOFEMORAL INSTABILITY

Proefschrift

ter verkrijging van de graad van doctor
aan de Radboud Universiteit Nijmegen
op gezag van de rector magnificus prof. dr. J.H.J.M. van Krieken,
volgens besluit van het college van decanen
in het openbaar te verdedigen op

woensdag 30 oktober 2019

om 12.30 uur precies

door

Anneke Rood

geboren op 10 januari 1982
te Eindhoven

PROMOTOREN
Prof. dr. A. van Kampen
Prof. dr. ir. N.J.J. Verdonschot

COPROMOTOREN
Dr. ing. S.A.W. van de Groes
Dr. S. Koëter (Canisius Wilhelmina Ziekenhuis)

MANUSCRIPTCOMMISSIE
Prof. dr. M.J.R. Edwards
Prof. dr. R.L. Diercks (UMCG)
Dr. D. Meuffels (Erasmus MC)

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CHAPTER 1 | INTRODUCTION

Patellofemoral instability is associated with the patella giving way, lateral maltracking, subluxation or complete dislocation. Patella dislocation is first described in 1829 in the Medico-Chirurgical Review in an article entitled Curious Cases of Dislocation of the Patella Outwards.26 A patient was treated non-operatively. "He was laid upon the left side, and his right ankle was grasped by a comrade who suddenly carried the heel back to the hip, thus bending the knee to the outmost. This motion was hardly completed when the patella audibly returned into its socket. "A second case described was operated on because the patella could not be reduced manually. They released the quadriceps tendon and the patellar ligament and subsequently opened the joint.

However, the patella could still not be reduced and the wound was closed. Unfortunately, the patient died eleven months later due to an on-going post-operative infection. The surgeon believed that it was not the surgical intervention but the persistent malposition of the patella that caused the infection. Although the authors state that "it is natural enough that the doctor should hold this opinion", even at that time they doubted this bold statement. Nowadays, even though there is much more understanding about patellofemoral instability, many unresolved issues regarding the best treatment for a particular patient with patellofemoral instability still remain.

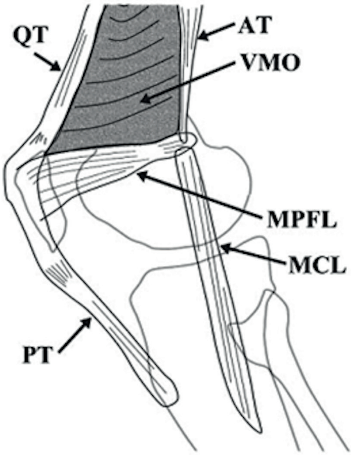
EPIDEMIOLOGY

In most cases, patellar dislocations occur in adolescents and young adults while practicing sports. The incidence of primary patellar dislocations varies from 2:100.000 (30-50 years) up to 31:100.000 (10-20 years).[20,43,44] It affects women and men almost equally (respectively 5.4:4.6). After a primary dislocation in seventeen per cent of the cases, a patellar dislocation re-occurs. After a second dislocation the risk on recurrence is at least fifty per cent.[43,44] The younger the patient, the higher the risk of recurrent dislocation due to underlying or acquired anatomic abnormalities.

AETIOLOGY

The most common cause of patellar dislocation is an indirect trauma to the knee during sports. If the quadriceps muscle is tensioned, the lower leg is externally rotated and the knee mildly flexed, a high lateral force arises on the patella. Because the patella is not fully captured into the bony ridges of the trochlea during the first 30 degrees of flexion, the patella is able to dislocate laterally under these circumstances. Medial dislocations are very rare and almost always caused by previous surgery. An inherited lack of stability due to anatomical factors can also contribute to recurrent patellar dislocations.

Figure 1: Anatomy of the Medial PatelloFemoral Ligament (MPFL)



(Rehman I, Smith CF - Orthopaedic Surgical Anatomy Teaching Collection (2002) Open-I)

Patellar stability is established by passive (bony and ligamentous) and active stabilizers. The bony relations between the concave trochlea and the convex articulating side of the patella are important. Dejour et al. showed that in 90% of patellofemoral instability patients trochlear dysplasia was present.[8] Leg axis and malrotation of femur and tibia can also play an important role. Passive stabilizing soft tissues are the lateral and medial retinacular tissues including the Medial Patello Femoral Ligament (MPFL). This is a V-shaped thickening of the medial retinacular structure with its origin just behind the medial epicondyle and the insertion on the proximal 1/3 of the medial patella rim.[1,16] (fig. 1) During a patellar dislocation this ligament is damaged in almost every case.[33]

In most cases the MPFL ruptures on the patellar side.[12] Biomechanical studies have shown that if the knee flexes from 0-30°, the MPFL is responsible for 50-60% of the total force that is needed to prevent dislocation of the patella. The length of the patellar tendon is also crucial in patellar stability, because a longer tendon causes a patella alta. Starting at an extended position, the patella will normally reach the trochlea at about 20 degrees of flexion. A patella alta, therefore results in a longer trajectory where the patella is fully dependent on soft tissue for stability. Active stabilizators are the quadriceps muscles, in particular the vastus medialis obliquus muscle. If there is an imbalance between the forces exerted by the medial- and lateral quadriceps muscles can also cause patellofemoral complaints. Recurrent instability can be caused by a developmental abnormality or a posttraumatic damage to the stabilizing structures. Most often the cause is multifactorial. To make (or exert) a good plan for treatment it is important to find and treat the anatomical abnormalities. Extra-articular causes of patellar instability can be related to malrotation of the lower leg, coronal deformities (valgus leg axis), hyper laxity, weakness and dysbalans of the lower extremity muscles. Joint related causes of instability are patella alta, trochlear dysplasia, lateralization of the tibial tubercle and insufficient mechanical properties of the medial soft tissues in particular the MPFL. These joint related deformities are significantly correlated with recurrent patellar dislocations.[8]

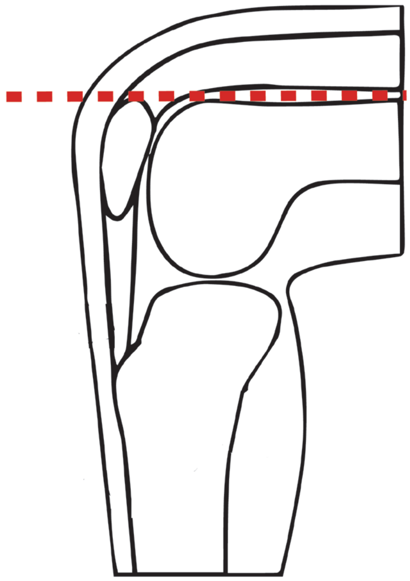
CLINICAL PRESENTATION AND PHYSICAL EXAMINATION

After an acute patella dislocation, patients experience a painful, swollen knee due to hemarthrosis. In contrast to other dislocations, the patella usually reduces spontaneously. If this does not happen, the knee has to be extended slowly while gently accompanying the patella until it reduces into the trochlea. If the acute phase is over, the main complaints will be pain surrounding the patella and giving way during short rotational movements and sports. Physical examination in the acute phase is often difficult because of hemarthrosis and pain. After several weeks post-dislocation testing the stability of the knee is much easier. In general, examining the patient has to include a consideration of the leg axis for malalignment including femoral anteversion, external tibial rotation, genu recurvatum, genu valgum and subtalar pronation because these are associated with patellar instability. Joint hypermobility is assessed using the Beighton Scoring System on a 9-point scale testing the fifth finger, thumb, elbow, knee and spine.[2]

Specific patellar stability tests are:

• *Patella glide test.*
With this test the lateral displacement of the patella is measured. The patient is in supine position with the knees extended. The examiner manual pushes the patella laterally and compares this to the contra lateral side. If the patella can be translated more on the affected side, this indicates that the MPFL is damaged.

Figure 2: Clinical measurement of patellar height



• *Apprehension test.*
The patient lies in supine position with completely relaxed legs. Push the patella laterally, if the quadriceps muscles retract by reflex this directs to patellofemoral instability.

• *Patella alta.*
Examine for a high riding patella. Normally, with the knee 90° flexed, the upper margin of the patella should be at the level of the anterior border of the femoral shaft. If the upper margin is higher, this is indicative of patella alta. (Fig 2)

• *J-sign.*
Look at the patella while extending the knee from a flexed position, both actively and passively. The J-sign is seen when the patella shifts abruptly laterally when exiting the trochlear groove as extension progresses, similar to an inverted J. This may indicate a dysplasia of the trochlea.

IMAGING

Conventional X-ray

A conventional, true lateral X-ray of the knee in 30 degrees of flexion is mandatory for two reasons. The first is to measure patellar height. There are several measurements described. One of the best measurements is the Caton-Deschamps ratio, which quantifies the ratio of the articulating surface of the patella and the most distal point of this measurement to the ventral surface of the tibial plateau.[30] Using Caton-Deschamps, a ratio of 1.2 or higher proves a patella alta. (Fig 3)

Figure 3: Measuring patellar height with the Caton-Deschamps ratio

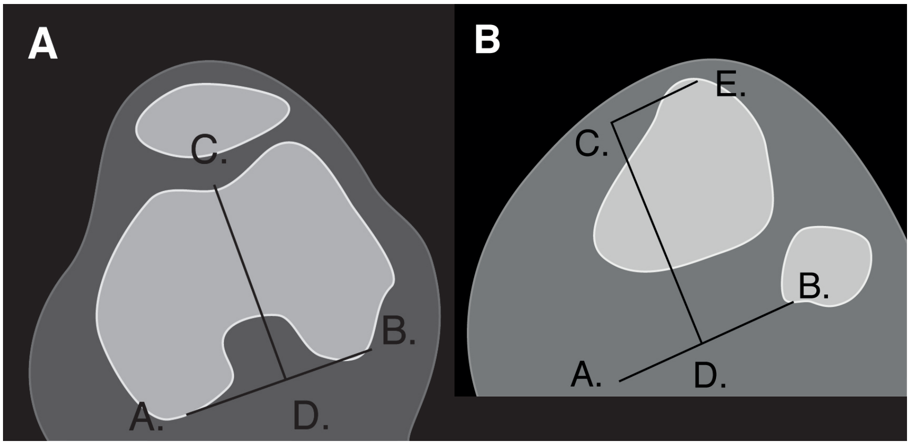
Secondly, a true lateral X-ray of the knee can reveal a crossing sign as a consequence of trochlear dysplasia. The crossing sign is positive when the line of the deepest point of the trochlear groove crosses the anterior border of one or both condyles.[6,28] (fig. 4) For this assessment it is crucial that the image is perfectly lateral, because a rotational error of only 5° can give both false positive as false negative outcomes.[17] In case of more severe dysplasia the trochlea is convex, with a bump on the proximal side of the trochlea. (fig. 4) This bump causes maltracking of the patella.

Figure 4: Crossing sign and trochlear spur

Computer Tomography (CT) and Magnetic Resonance Imaging (MRI) scan
The sulcus angle is also a method to determine trochlear dysplasia. It measures the depth of the trochlear groove and is normally between 132° and 144°. A wider angle points towards a dysplastic trochlea. The method to measure the sulcus angle is not very reliable on the patellar view taken with conventional x-ray imaging, but best measured with a CT or MRI-scan (fig. 5). The advantage is that with a scan you can make axial coupes to look at the anatomic relations of the patella and trochlea. Normally the patella is congruent with the trochlea. An enhanced patellar tilt can indicate insufficiency of the medial soft tissue stabilizers (most importantly the MPFL) with or without a short lateral retinaculum.[8] The most reliable measurement is in full extension, or only mild flexion of 15 degrees because in flexion the patella glides in the trochlea so the tilting can be reduced and therefore underestimated. The cut-off point of pathological patella tilting depends on the type of measurement used.[5] The position of the tibial tubercle relative to the trochlear groove (TT-TG) can be determined on a scan. If the tubercle is situated too laterally on the tibia, there is a dynamic lateralisation when contracting the quadriceps muscles. On a transverse series a line is drawn parallel to the posterior femoral condyles.

A second line is drawn, perpendicular to the first line and exactly through the deepest point of the trochlea. Parallel to this line a third line is drawn through the middle of the tibial tubercle. The distance between these two lines is the TT-TG (fig. 5) and is excessive if it is more than 15-20 mm on a CT –scan in full extension.[9,27]

Figure 5: Measuring TTD and patellar tilt with a CT-scan



Measuring the TT-TG on an MRI-scan, the cut-off points are dependent on the amount of flexion in the knee. The tibia is externally rotated relative to the femur as the knee approaches terminal extension. This kinematic relationship has been termed the "screw home mechanism" and it may account for the variability in these measurements, depending on patient positioning. Earlier studies showed that with increasing knee flexion, the distance between the tibial tubercle and the trochlear groove decreases. In practice, significant variations in knee flexion occur during MRI because different knee coils because leg position is frequently dictated by patient comfort.[13,15,23,31,34] So although the TTTG distance can be measured on both CT and MRI with excellent intrarater and interrater reliability, these distances measured on CT and MRI may not be considered equivalent. Controlled, reproducible positioning certainly within each centre and ideally from centre to centre is vital.[14]

In addition, these scans can be used to calculate the lateral trochlear inclination.[39,40] The lateral trochlear inclination is a measure of the angle created between a line adjacent to the posterior edges of the femoral condyles and a second line tangential to the subchondral bone of the lateral trochlear facet.[35] By comparison, lateral radiographs generally underestimated trochlear dysplasia compared with axial MRI. When history and examination establish the diagnosis of patellofemoral instability clearly and there is not a large effusion or radiographic evidence suggesting osteochondral injury, an additional MRI is not always necessary.[27]

TREATMENT

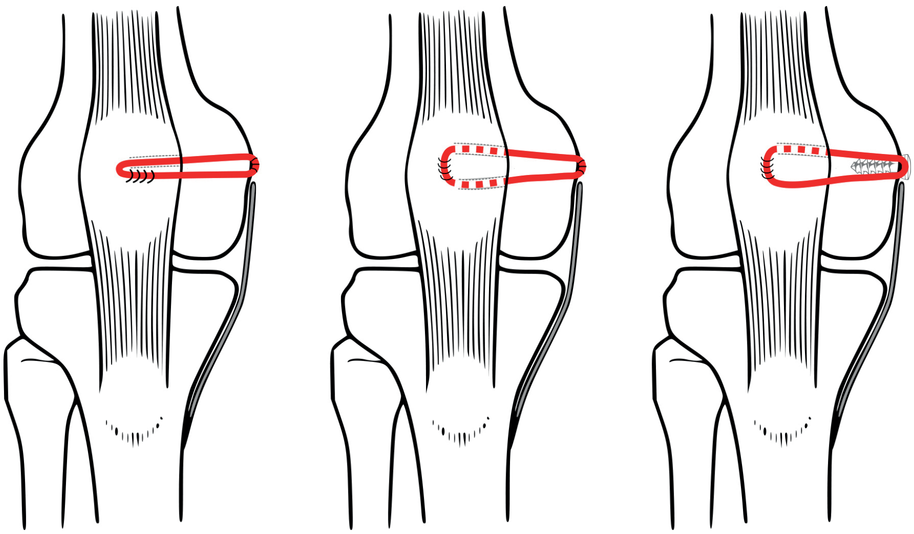
Immobilization

After a primary patellar dislocation, the treatment is preferably conservative.[3,25] Although surgical stabilization of the patella results in a reduction of recurrent instability, there is no difference in functional outcome compared to conservative treatment. In fact, surgical treatment in these cases can result in more pain, surgical complications as well as higher incidence of patellofemoral osteoarthritis.[25,36-38] Many different types of conservative care are described. This varies from a non-weightbearing long leg splint for six weeks to a brace with full weight bearing. From the several patellar-stabilizing braces there are no clinical trials available to determine their value. Shorter duration of immobilization could possibly increase the risk of recurrent dislocation; conversely, longer duration of immobilization tends to lead to quadriceps muscle strength loss, reduction in range of motion, and cartilage degeneration.[11,22] Theoretically, weight bearing muscle contraction produces a force vector that compresses the patella against the trochlea, improving stability. In summary: the best conservative treatment option is still unclear.

MPFL reconstruction

If the medial soft tissues are damaged and provide insufficient stabilisation, an MPFL reconstruction may be considered. There are several types of reconstructions described in literature; they can be divided into static and dynamic reconstructions. In a static reconstruction the graft (generally hamstring tendon or part of the quadriceps tendon) is attached to a specific point, typically targeting the isometric point1, on the medial femoral condyle with an anchor or screw. The dynamic type uses a hamstring graft that is looped around the adductor tendon or through a part of the medial retinaculum (fig. 6). The fixation method on the patella also differs greatly and depends on the type of graft used. The quadriceps graft is already fixed to the patella. The hamstring graft can be fixated with anchors, bone tunnels or simply sutured to the patellar periosteum. This dynamic MPFL reconstruction has no risk of damaging the physis and therefore could be a good technique for skeletal immature patients.

Figure 6: Different types of MPFL reconstructions



A. Dynamic B. Partial dynamic C. Static

Tibial tubercle osteotomy

In case of a patella alta or a lateral position of the tibial tubercle, a tibial tubercle osteotomy can be performed. The amount of distalization can be measured preoperatively using a patellar height index. When the TT-TG distance is abnormal, a medialization of the tubercle can be performed. Several techniques are described. The most utilized techniques are the Elmslie-Trillat-procedure, the Fulkerson osteotomy, the sliding osteotomy (fig 7) and a technique where the tubercle is completely detached from the tibia (fig. 8).[4,10,18,24,42] It remains unclear which technique is superior. There is little evidence that a full detachment of the tubercle leads to poor vascularization and possible higher failure as a consequence of non-union of the bony attachment sites. Secondly, the step cut that is made using this technique is considered a stress riser, which increases the risk of tibial fractures and is therefore discouraged by some authors.

Figure 7: Sliding, self-centering Tibial Tubercle Osteotomy

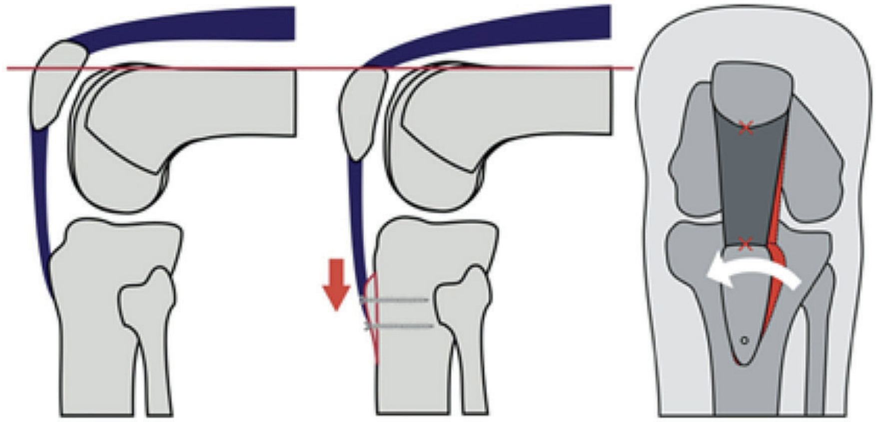
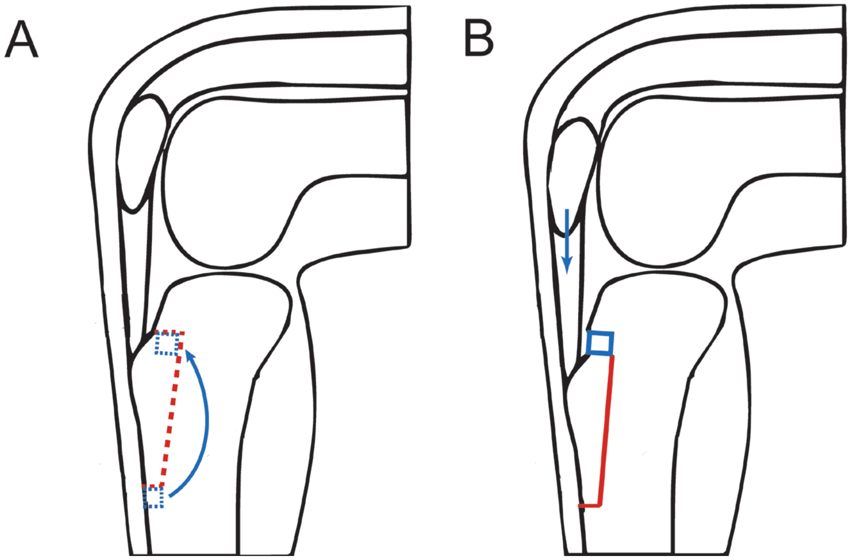


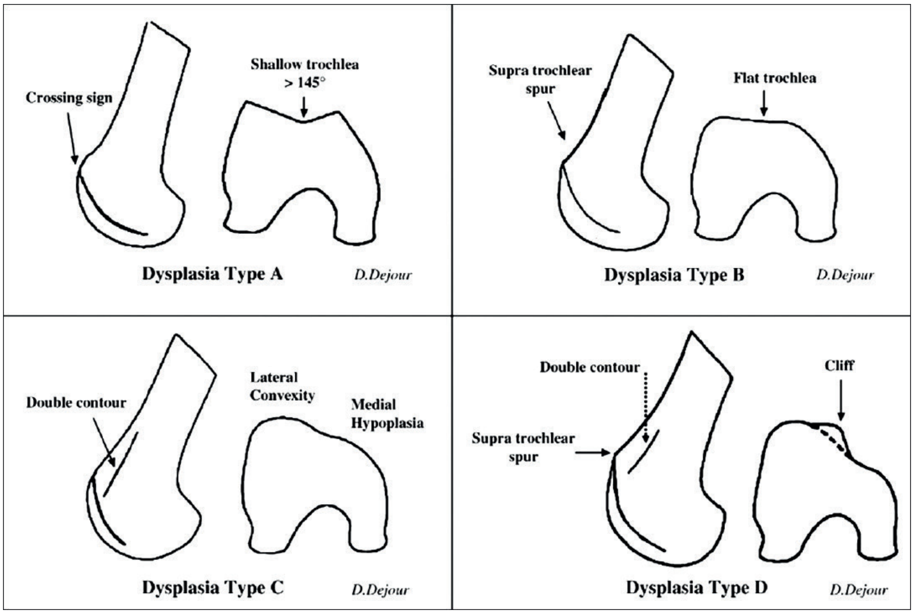
Figure 8: Detaching, V-shaped Tibial Tubercle Osteotomy



Trochleoplasty

It is crucial to determine the type of trochlear dysplasia to decide which treatment is necessary. The classification system of Dejour for trochlear dysplasia is widely used and can be determined with conventional radiographs. (fig. 9)

Figure 9: Dejour classification of trochlear dysplasia



Reddy KR, Reddy NS - Indian J Orthop (2012) Open-I, Indian J Orthop. 2012 Mar-Apr; 46(2): 242–245.

If the dysplasia is mild, an MPFL reconstruction can be sufficient with or without a tibial tubercle transfer.[19] If the dysplasia is severe, a trochleoplasty can be performed. Several techniques are described and can be divided into two types of plasties: lateral wall elevation and deepening of the trochlea. When elevating the lateral wall, the lateral side of the trochlea in lifted with an open osteotomy with a bone wedge. Hereby creating a concave shape of the trochlea (fig. 10). However, if there is a trochlear bump this procedure will not be sufficient. In those cases, a trochlear deepening can be performed.[7,21] This is a challenging procedure, where the cartilage with a thin subchondral bone layer of the trochlea is peeled off to deepen the subchondral bone of the trochlea groove. The advantage is that there is a lower risk of overstuffing the patellofemoral joint compared to the lateral wall elevation technique. Secondly, if a bump is present, this can also be removed. This procedure is a much more demanding technique compared to elevation of the lateral wall. A recent expert meeting has stated that a deepening trochleoplasty is considered when all of the following are present: a J-sign, a bump or supratrochlear spur more than 5 mm and a convex proximal trochlea.[27]

Combination

Frequently there is more than one problem of the patellofemoral anatomy, so these previous described procedures can be combined to create a stable situation. For example, Laprade advocates performing a MPFL reconstruction in conjunction with any trochleoplasty procedures.[19]

OUTLINE OF THIS THESIS

Patellofemoral instability is a common orthopaedic problem particularly in young patients. Although considerable literature exists about the analysis and treatment of this condition, there are still many issues to be resolved and consensus about a treatment algorithm is definitely missing. We know that in first-time patellar dislocations without substantial anatomic abnormalities, conservative treatment is preferred. The optimal conservative treatment, however, remains unclear. Balancing immobilisation for soft tissue healing to prevent recurrent dislocations and early active mobilisation to prevent muscle waste is key. Little is known on this specific topic and no solid, prospective studies comparing different types of immobilisation of the knee after a patellar dislocation existed starting this thesis. To look further into this, **chapter 2** describes a prospective, randomised trial comparing two different types of conservative treatment after a first-time patellar dislocation; tape versus cast immobilisation.

If conservative treatment fails or the anatomical abnormalities are too distinct, surgical stabilisation of the patella is indicated. Over the last decade, reconstructing the MPFL has gained huge popularity. Numerous techniques of MPFL reconstruction are described and can be divided into static and dynamic reconstructions. Almost all studies published in the past 18 years consider the static variant. As far as we are aware of, there are no studies available comparing these two types of MPFL reconstructions. **Chapter 3** describes and illustrates the technique of the dynamic MPFL reconstruction using a hamstring autograft. In **chapter 4** we compare different conditions of the patellofemoral joint in a cadaver study thereby quantifying patellofemoral contact pressure and contact area. The cadavers were tested in a loading apparatus comparing the native situation in an intact knee and the situation after three types of MPFL reconstructions.

Although MPFL reconstructions have become more common, studies assessing complications after this specific surgery in large groups of patients were lacking. A systematic review by Shah et al[32] in 2012 reviewed 25 articles which described a total number of pooled data of only 629 knees. A second review by Stupay et al[41] in 2015 analyzed another 19 studies analyzing 650 knees. Again, these results are mainly about the static reconstructions of the MPFL. To assess the specific complications after a dynamic MPFL reconstruction, **chapter 5** describes a large cohort of almost two hundred knees.
Surgical treatment of stabilizing the patella in the skeletally immature patients creates additional challenges. Because growth is not to be disturbed, damage to the physis should be avoided in all cases. Unfortunately, unstable patellofemoral joints in very young patients are most of the time caused by anatomical disorders and request bony procedures. Performing the dynamic MPFL reconstruction we described earlier in **chapter 3**, no bone tunnels or osseous fixation points are used and could therefore be a good alternative for this specific group of patients. We describe the complications and clinical results in **chapter 6**.
The 'MPFL-hype' has resulted in claims that almost every instable patella can be fixed with an isolated MPFL reconstruction, regardless of the anatomical disorders. In large parts of the world, especially the United States of America, osteotomies around the knee are hardly performed and replaced by soft tissue procedures. Fear for non-unions and tibial fractures complicating tibial tubercle osteotomies (TTO's) are preventing surgeons to pass on the skills of performing osteotomies. To look further into this, we analyse the complications of a detaching, V-shaped TTO (**chapter 7**) and a self-centring TTO (**chapter 8**) in two large cohorts.

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2

CHAPTER 2

Tape versus cast for non-operative treatment of primary patellar dislocation: a randomized controlled trial

Akkie Rood
Harm Boons
Joris Ploegmakers
William van de Stappen
Sander Koëter

Publication: Archives of Orthopaedic and Trauma Surgery 2012 Aug;132(8):1199-203

ABSTRACT

Purpose: We hypothesized that taping results in better short-term functional outcome and comparable redislocation rates.

Methods: In a prospective randomised clinical trial, 18 patients with a primary patellar dislocation ≥18 years old without accompanying fractures or previous surgery to the knee were included. After one week of dorsal splinting they were randomized for two groups: taping and cylinder cast immobilization. Physical examination and knee function according to the Lysholm Knee Scoring Scale were taken at 1, 6, 12 weeks and 1 and 5 year follow-up. We also compared the redislocation rates.

Results: Taping resulted in a significant better Lysholm score at 6 and 12 weeks post dislocation ($P<0.05$) and also after 5 year follow-up ($P<0.01$). Knee function was better at 1-year follow-up. There were no cases of recurrent dislocation.

Conclusion: Tape bandage immobilization seems superior to a cylinder cast even after five years.

Key Words: Immobilization, subluxation, conservative, patella

INTRODUCTION

Patellar dislocation is a very painful event where the patella dislocates in almost all cases to the lateral side of the knee.[1] Sixty-one percent of the primary dislocations occur during sporting activities and are mostly seen in adolescents and young adults.[1] The incidence of patellar dislocation varies between 31:100,000 (10-20 years), 11:100,000 (20-30 years) and 2:100,000 (30-50 years).[1-3] A male to female ratio of first-time dislocations is 4.6:5.4. Up to 44% will develop recurrent dislocations.[1-3] Dislocations of the patella are often complicated with osteochondral fractures or a tear of the medial patellofemoral ligament (MPFL). It is known that almost half of the patients who have had a patellar dislocation experience impairment as a result of the injury.[4] In the acute phase, the majority of dislocated patellae self-reduce spontaneously. If not, it needs to be reduced by simply extending the knee with mild pressure on the lateral edge.

The best treatment for primary patellar dislocation has been the subject of persisting controversy. Taping in this early phase is rarely done worldwide. Taping is more frequently used post-6 weeks as part of a rehabilitation program to reduce pain, increase psychological support and to facilitate VMO recruitment. Current treatment options include non-operative methods (bracing or cast immobilization), arthroscopic repair and a direct open surgical intervention. Several reports show that non-operative treatment is as good as direct surgical intervention in the case of primary patellar dislocation without osteochondral fractures which caused locking of the knee, even at long-term follow-up.[5-11] The indication for primary surgery (e.g., MPFL reconstruction) in acute, first-time patellar dislocation appears to have strict indications. [7,12]

The ideal non-operative treatment provides good and quick functional recovery and minimizes the chance of recurrent patellar dislocation. Cylinder cast immobilization has been frequently used in the Netherlands, and it theoretically allows for adequate healing of the medial retinaculum and the MPFL. But immobilizing the knee may have a deleterious effect on ligament strength, joint cartilage, and prolonged weakness of the bony origin of ligaments.[13-15] This may result in muscular hypotrophy, flexion deficit, and potential poor (short term) functional outcome. In an attempt to facilitate a quicker functional rehabilitation other non-operative treatments like taping and bracing have been the subject of several retrospective clinical studies.[6,16,17] These treatment modalities offer the advantage of a quicker functional rehabilitation, but may result in elongated healing of the MPFL.

Our hypothesis was that taping gives better functional results with comparable redislocation rate. The aim of this prospective clinical trial was to compare taping to a cylinder cast immobilization with a 5-year follow-up.

METHODS

A randomized controlled, parallel-group study was performed at the Canisius Wilhelmina Hospital in Nijmegen, the Netherlands. Patients who presented themselves at the emergency department with a primary lateral patellar dislocation were included. Exclusion criteria were previous operation on the knee, accompanying (osteochondral) fracture of the knee, neurologic disorders (e.g., paralysis), previous patella dislocation or other abnormality to one or both knees. Patients had to be at least 18 years old because of the local medical ethical commission, who approved of the study. They all signed an informed consent. The patellar dislocation was confirmed by the examiner by anamnesis and physical examination. In four cases the dislocated patella was replaced by manual reduction, three were reduced in the ambulance. In the other 13 cases the patella repositioned spontaneously. After inclusion, patients were randomised for a cylinder cast or taping by picking an envelope which contained the treatment for that patient. Whereas patients and physicians allocated to both intervention groups were aware of the allocated arm, outcome assessors and data analysts were kept blinded to the allocation. The first week after dislocation, patients were treated with a pressure bandage and a dorsal long leg splint. During this week both groups were treated with nadroparine (Fraxiparine®, 2850E) to prevent thrombosis. After a week, they either received a cylinder cast fixed in full extension or a tape for further treatment for another 5 weeks. Taping especifically immobilizes the patella to prevent lateral re-dislocation but allowed 30-40° of flexion, it did not limit extension. It was built up in three layers (figure 1). All casts and tape were applicated by a professional cast master. At week 2, 3, and 4 the quality of the casts was evaluated and the taping was re-applied to prevent loosening. Both groups were allowed to full weight bearing. Immediately after the tape or cast was removed (6 weeks after dislocation) an intensive training of the quadriceps started under supervision of a physiotherapist following a strict protocol. In a standardized protocol isometric and isotonic exercises were given to strengthen quadriceps muscles. Primary outcome measurement was the subjective knee function, with redislocation rate as secondary outcome.

Figure 1: Taping technique used during this trial.

To measure the subjective function of the knee, the Lysholm Knee Scoring Scale18 was taken at 1, 6, and 12 weeks and at 1 and 5 years post dislocation. Physical examination included knee function and hypotrophy of the quadriceps. Thigh hypotrophy was defined as the smaller thigh circumference registered by measuring 10 cm proximal of the superior pole of the patella. The contralateral knee was used as reference.

Study population

From 2000 to 2003, 20 patients were randomised for 1 of the 2 treatments. Almost half of the patients who presented themselves with a patellar dislocation at the emergency department had to be excluded, because they were under 18. One patient in the cast group was lost to follow-up at 1 year. Another patient in the tape bandage group reported a previous patellar dislocation at the first follow-up and was excluded. This leaves us with 18 patients which provided a complete set of data—tape group: 6 males and 3 females with a mean age of 26 (18-44); cast group: 6 males and 3 females with a mean age of 29 (19-33). In both groups, there were no cases of recurrent (partial) dislocation. Baseline data were comparable for the two groups.

Statistical analyses

For the purpose of statistical analysis, variables regarding patient characteristics were grouped in the following manner: based on power analysis it was calculated that for this study 10 patients per group would be necessary to have a statistical significant difference by the Lysholm Knee Scoring Scale, assuming 15 points difference in the Lysholm Knee Scoring Scale between the two treatments with a power of 90%.

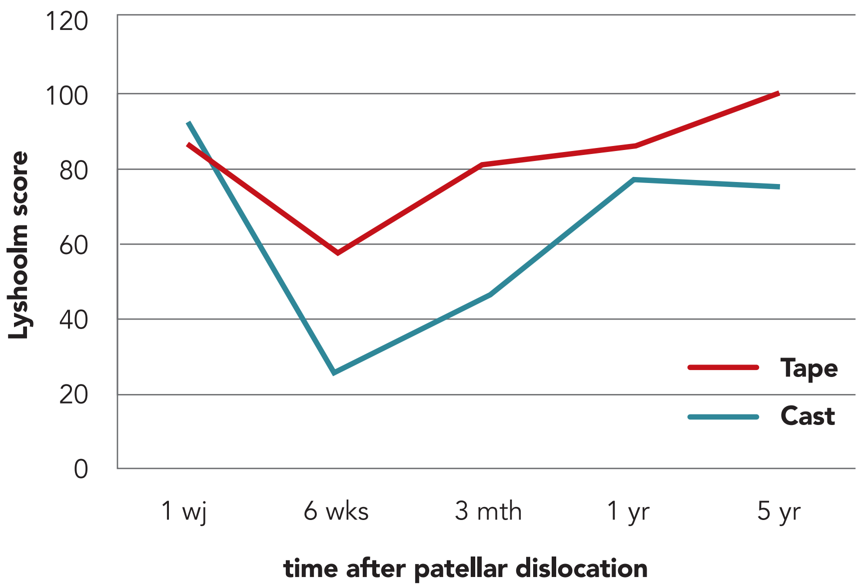
Differences in knee function according to the Lysholm Knee Scoring Scale and quadriceps hypotrophy between groups of patients were tested for statistical significance by using the Mann-Whitney U test. P values <0.05 were considered to be statistical significant. All statistical analyses were performed using the software package SPSS 14.0 for Microsoft Windows (SPSS Inc., Chicago, IL, USA).

RESULTS

Knee function results according to the Lysholm Knee Scoring Scale

In both groups the knee function according to the Lysholm Knee Scoring Scale were the poorest after 6 weeks, with means of 58 for the tape group and 26 for the cast group. This is a significantly better score in favour of the tape group (P = 0.001). As illustrated in Fig. 2, after 12 weeks and 5 years, there was also a significant better score in favour of the tape group (P = 0,019 vs. P = 0.008) (Table 1; Fig. 2). After 5 years, the tape group scored a maximum knee function score of 100 compared to 76 in the cast group. At 1 year, the tape group also scored better, but this difference wasn't significant. Scores in both groups improved until the 5-year appointment.

Figure 2: Lysholm knee scoring scale at 1,6 and 13 weeks en 1 and 5 years after primary patella dislocation in group T (taping) vs group C (cylinder cast).

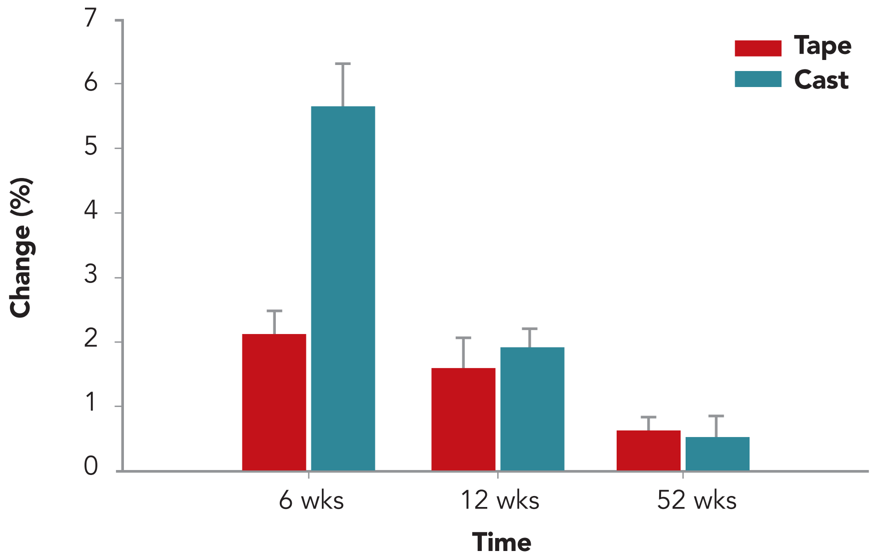


wk: week, wks: weeks, mth: months, yr: year.

Physical examination

At 6 weeks post dislocation, the hypotrophy of the quadriceps in the tape group was significantly less compared to the contralateral knee (5.7 cm vs. 2.1 cm, P < 0.001, Fig. 3). At longer follow up (12 weeks, 1 and 5 years) there was no difference between the groups. However, the range of motion of the knee scored better in the tape group at 12 weeks and 1 year. In the average flexion of the affected knee, there were no significant differences between the groups at 6 weeks and 5-year follow-up.

Figure 3: Hypotrophy of the quadriceps muscle of the injured knee. Difference in circumference of the quadriceps muscle compared to the contralateral knee, measured 10cm aboven the patella, in degrees. Values are mean ± SD. Wks = weeks.



Complications

One case of deep venous thrombosis (DVT) occurred in the cast group, despite thrombosis prophylaxis. After the diagnosis was confirmed with duplex imaging, the patient started therapy by using acenocoumarol (vitamin K antagonist) for 6 months. There were no cases of DVT in the tape group. In the tape group, three patients had mild irritation of the skin due to the tape. They were all able to finish the tape treatment, no extra care was necessary. In both groups, there were no cases of recurrent dislocation.

DISCUSSION

Our results indicate superiority of taping over cylinder cast immobilization. Even after 5-year follow-up, patients treated by taping still had a significant better knee function according to the Lysholm Knee Scoring Scale compared to the cast group. There was no difference between the groups in recurrent dislocation. The functional scores at 6 weeks are better with the tape treatment because of the mechanical impairment of the plaster cast, but subjective scores at 6 and 12 weeks are also significantly better when treated by tape immobilization. The significant difference in thigh circumference at the six weeks follow up shows that tape immobilization decreases the amount of muscle loss, probably leading to better functional scores and earlier recovery. Primary patella dislocation may result in prolonged rehabilitation and recurrent dislocation.[19-21] Previous studies reported knee function according to the Lysholm Knee Scoring Scale of 87-89 after conservative treatment with a walking cast at 7- to 8-year follow-up.[5,6] Functional results in our cast group were worse, with a mean score of 76, which we cannot explain. The results of the tape group, however, were significantly better, with a mean score of 100. And even if we compare this to the scores in other studies, this is still an improvement. Because the hypotrophy and range of motion are comparable after 5 years, but the knee function according to the Lysholm Knee Scoring Scale is still so different, there has to be another explanation. We did not look at the differences of activity levels between the patients, before and after dislocation. It is hard to tell if this could affect our result. We found no recurrent dislocation in both groups. In literature, a recurrence percentage of 27% is reported.[5,6] Limitations of our study include the limited number of patients and the non-normal distribution of the patient group. In theory, the study can be underpowered. This may result in equal redislocation rates for both groups. Based on previous studies (with reported redislocation rates of 27%) two to three redislocations in either group were expected. If tape bandage treatment would have resulted in poorer healing of the medial retinaculum, one or more redislocations are plausible. Since we found no redislocation in either group, we believe that the difference in medial retinaculum healing cannot be that comprehensive.

In conclusion, the present study tape bandage revealed higher values in terms of knee function compared with cast immobilization both in the short and medium term follow up. To establish the true redislocation rate after tape treatment of a primary patella dislocation, a further study with a larger number of patients is necessary.

Acknowledgements

There were no other contributors or sources of funding of this study.

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CHAPTER 3

Medial Patellofemoral ligament reconstruction for patellar instability

Albert van Kampen
Akkie Rood

Publication: Efost Knee surgery volume 1: soft tissue.
Henrique jones et al. 2016, Chapter 15.

INDICATIONS

Medial patellofemoral ligament (MPFL) reconstruction is indicated:

- In the skeletally mature patient with traumatic patellar instability without anatomic abnormalities like trochlear dysplasia
- In combination with other surgical procedures to stabilise the patella.

PRE-OPERATIVE ASSESSMENT

Clinical Assessment

Patient history

- First time dislocation is usually traumatic in nature
- The patient may describe multiple lateral dislocations of the patella, with or without spontaneous resolution
- There might be a feeling of instability, resulting from inhibition of the quadriceps muscle due to pain
- A locking sensation can occur in full extension due to a involuntary reflex contraction of the quadriceps and hamstrings: this functions to prevent contact between the cartilage of the patella and trochlea

Physical examination

Patellofemoral instability can be due to insufficiency of the MPFL, a patella alta, or dysplasia of the trochlea. Physical examination should be used to differentiate between these causes. The following tests can be used:

- Apprehension test: with the knee in full extension, push the patella laterally. The test is indicative of patellofemoral instability if the patient finds this manoeuvre unpleasant.
- Patellar glide test: with the knee in full extension, translate the patella medially and laterally. When the patella can be translated laterally more at the affected side than at the unaffected side, this indicates a traumatic rupture of the MPFL.
- Examine the knee in 90° of flexion. The upper margin of the patella should be at the height of the anterior edge of the femur. If the upper margin is higher, this is indicative of patella alta.
- J-sign: ask the patient to actively extend the knee from a flexed position. The J-sign is seen when the patella shifts abruptly laterally when exciting the trochlear groove as extension progresses, similar to an inverted J. This indicates a lateral position of the patella in full extension, which might be secondary to dysplasia of the trochlea.

Imaging Assessment

Radiographs

- Plain anteroposterior and lateral radiographs may reveal a bony avulsion at the medial femoral insertion site of the MPFL (on the anteroposterior view), or on the medial site of the patella (on the patellar view). Either sign indicates an avulsion of the MPFL.

Magnetic resonance Imaging (MRI)

- MPFL rupture is a clinical diagnosis, and a MRI is not advised in the routine workup.

Timing for surgery

- Schedule surgery after inflammation around the knee has resolved.
- Do not perform surgery unless there have been multiple patellar dislocations.

SURGICAL PREPARATION

Surgical equipment

- Tendon stripper

Patient positioning

- Place the patient in the supine position. A knee support is helpful to position the knee in different angles of flexion.
- Do not use a tourniquet as this might influence the patellar tracking by putting pressure on the quadriceps muscle.

Further preparation

- No antibiotic prophylaxis is necessary.

SURGICAL TECHNIQUE

Exposure

- Make a vertical incision, medial to the tibial tuberosity, to expose the pes anserinus. Alternatively, make a more horizontal and more medial incision, exactly over the palpable semitendinosus.
- Open and expose the pes anserinus in order to identify the gracilis and

semitendinosus tendons. Taking care to divide any vincula, pass the tendon stripper over the hamstring tendon to harvest them.
- Prepare one end of the hamstring graft with a suture in order to make it more easily held during subsequent steps.
- Make a second incision of about 4 cm, along the medial border of the patella. Open the retinaculum using cutting diathermia, but leave the synovium intact.
- Finally, make a 1 cm incision at the femoral insertion site of the MPFL.

Tendon repair
- Dissect the synovial tissue and the medial retinaculum bluntly towards the medial epicondyle.
- Grasp the suture of the graft in the clamp.
- Make an opening in the retinaculum 1 cm posterior to the level of the medial epicondyle, by pushing the end of a clamp trough the tissue, from inside out. The adductor tubercle is found directly underneath.
- Palpate the tip of the clamp underneath the skin, and make a incision at this point (Figure 1 and 2).

Figure 1: The red arrow indicates the passage of the graft between the synovial layer and the medial retinaculum.

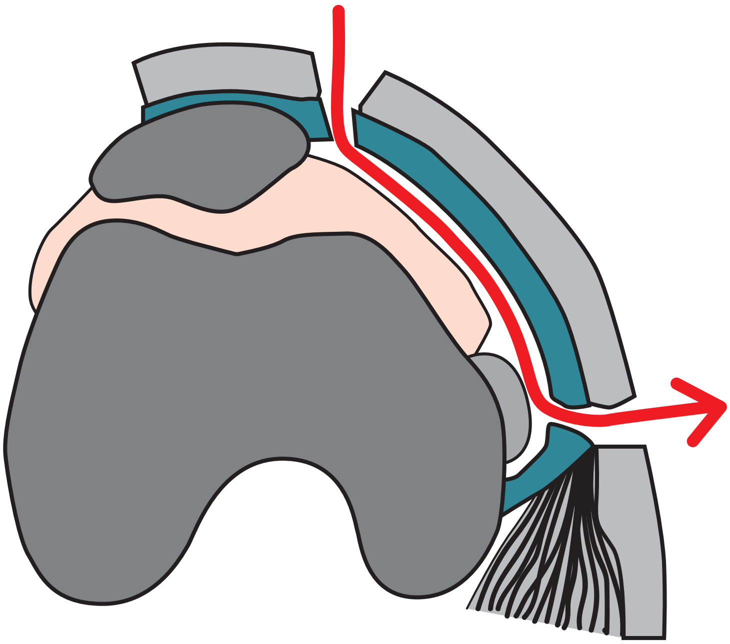
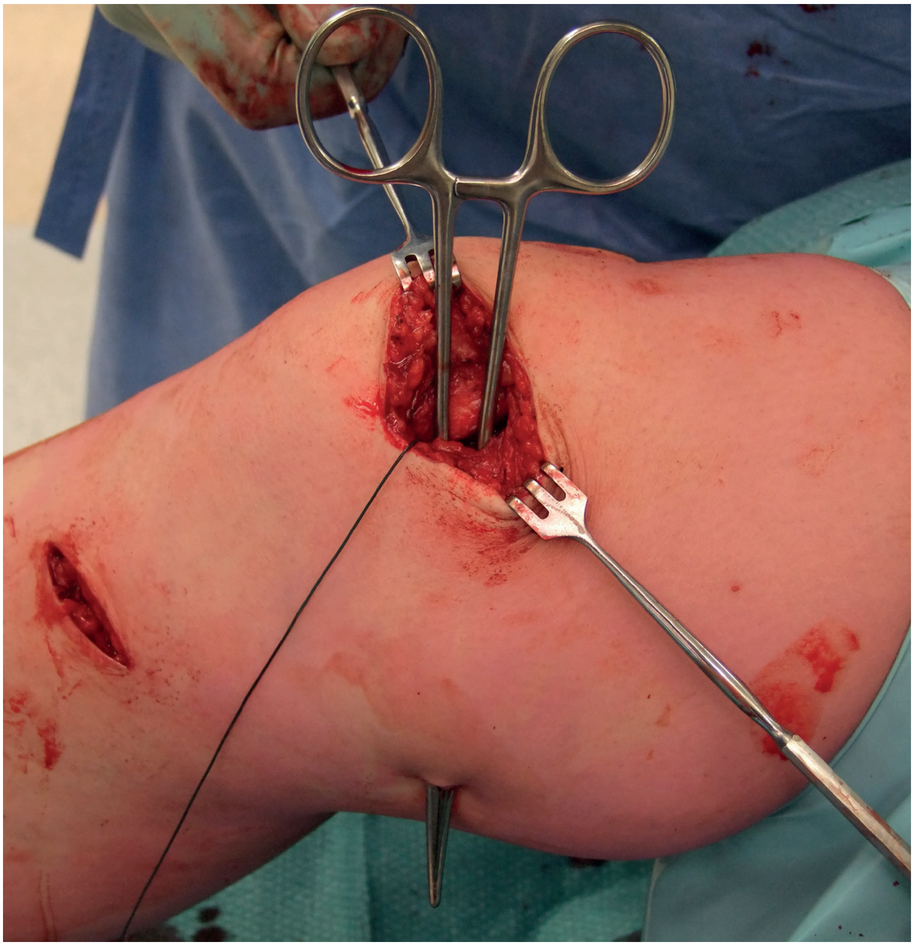


Figure 2: The first incision is made at the medial border of the patella. With a clamp the graft is past and an incision is made at the tip of the clamp in the area of the medial epicondyle.

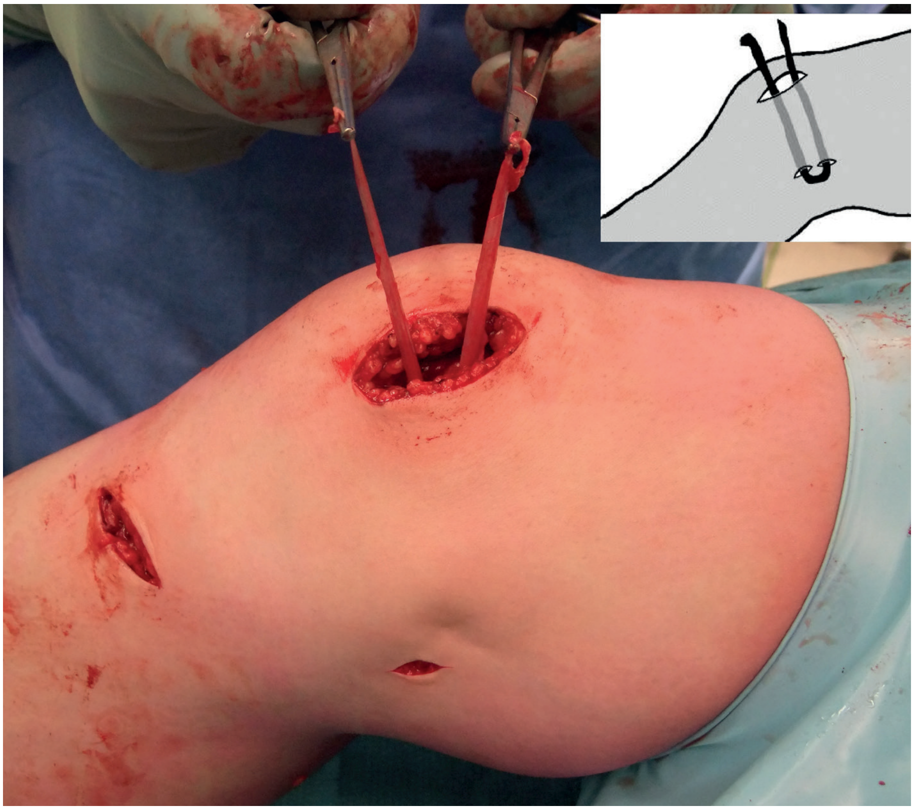


- Feed the graft through the incision. (Figure 3)
- Make a second opening in the retinaculum 1 cm more proximal and anterior.
- Grasp the suture with the clamp and retrieve the graft.

Figure 3: The graft is advanced underneath the retinaculum.

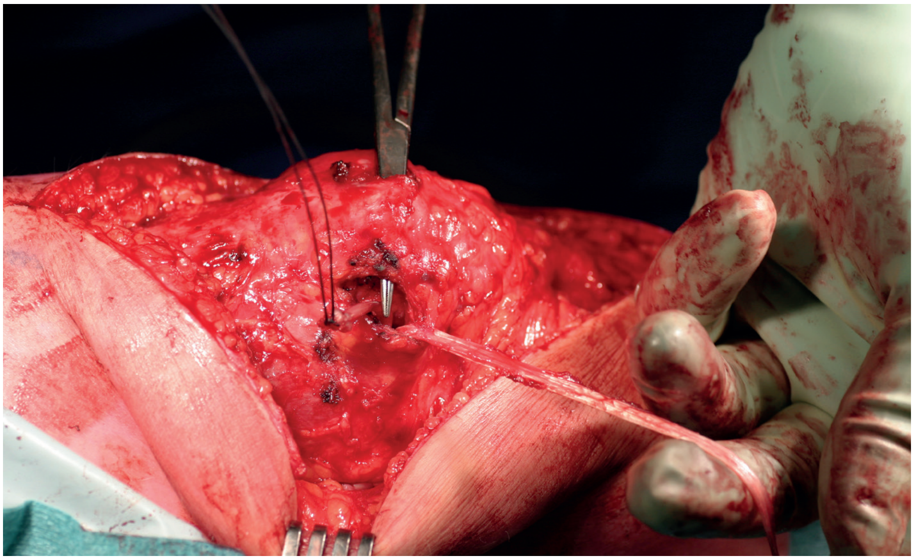
- Thread the graft through the first opening outside the retinaculum, loop it around the adductor tendon with a curved clamp, and lead it back inside through the second opening in the retinaculum. (Figure 4)

Figure 4: The graft is looped around the adductor tendon with a curved clamp, and led back inside through the second opening in the retinaculum.



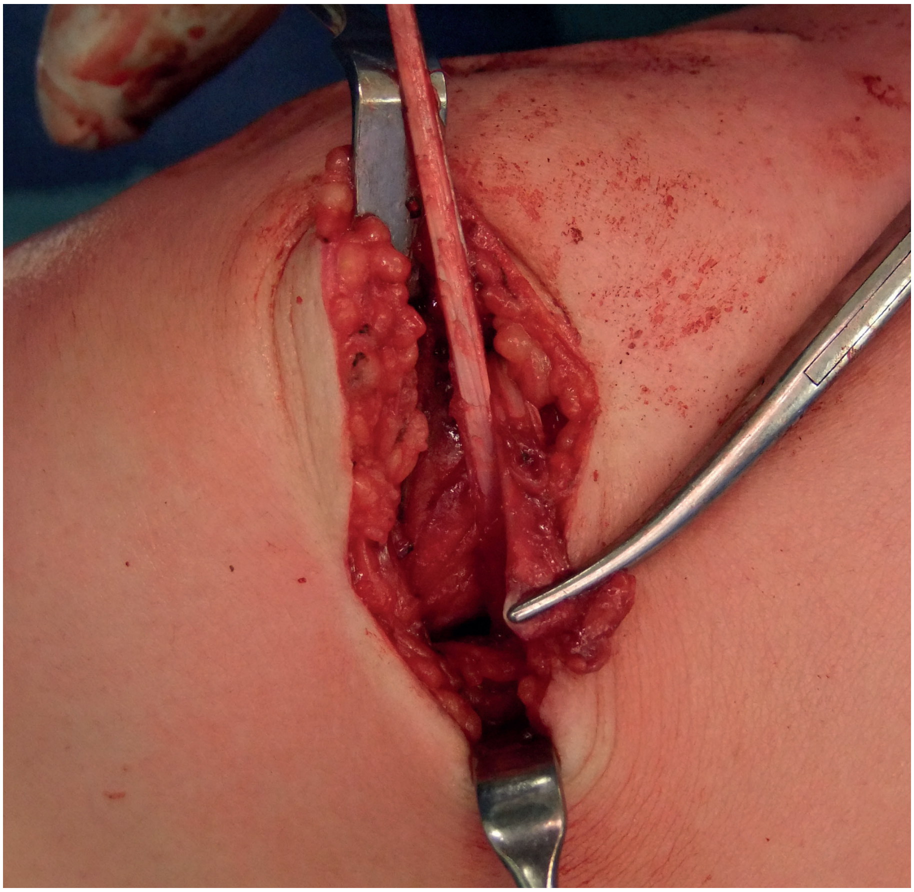
- Using a sharp rasp, make a subperiostal tunnel on the anterior aspect of the patella, from the midline to the proximal 1/3rd of the medial border. (Figure 5)

Figure 5: A subperiosteal tunnel is made at the proximal third of the patella starting at the middle of the patella, indicated by the clamp. One of the slips of the graft is advanced through this tunnel.



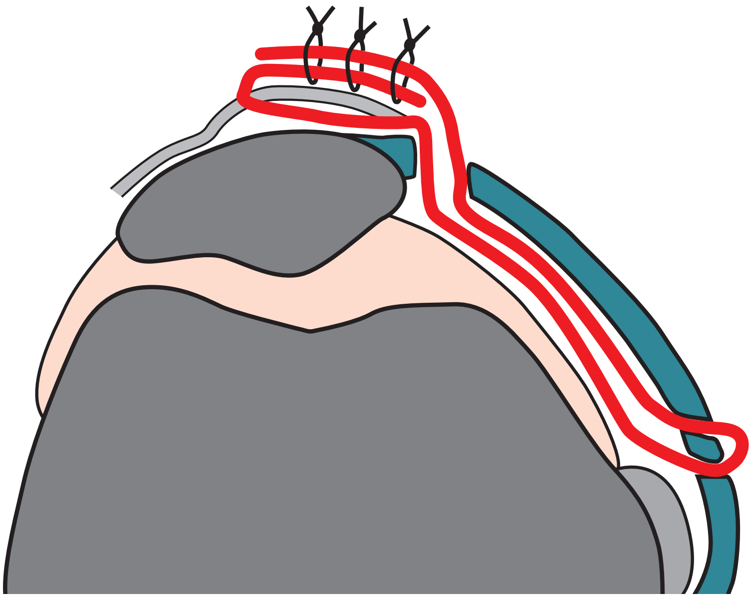
- Pull one end of the graft through this tunnel, flip it back on top of the patella, and pull it towards the medial side of the knee. (Figure 6)

Figure 6: The two slips of the graft are seen. The proximal slip is sutured on the patella, a clamp is used to tension the graft.



- After tensioning of the graft to approximately 2N in 30° of knee flexion, secure it by suturing the ends of the graft to each other and to the periosteum. A schematic representation of the end result is shown in Figure 7.

Figure 7: The schematic result is shown in red.



POSSIBLE PERI-OPERATIVE COMPLICATIONS

- It is advisable to have allograft hamstrings available if, in rare cases, the hamstring tendon is of poor quality.
- If graft placement is incorrect, the reconstruction may be too tight. Thus it is important to asses graft tensioning through a full range of flexion and extension of the knee joint, before closing the skin. If the tension is incorrect, release the sutures, which fix the tendon on top of the patella. The tension can then be adjusted and the tendon can be re-sutured on top of the patella.

CLOSURE

- No drainage is required.
- Close the subcutaneous tissue and skin in a standard fashion.
- Apply a simple wool and crepe dressing.

POST-OPERATIVE MANAGEMENT

- Permit full weight bearing immediately.
- Allow flexion upto 50° immediately. After 6 weeks maximal flexion is allowed.

OUTPATIENT FOLLOW-UP

- Review in the outpatient clinic at 6 weeks and 3 months postoperatively to evaluate knee function and clinical progress.

H7 FURTHER READING

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CHAPTER 4

Patellofemoral pressure changes after static and dynamic MPFL reconstruction

Akkie Rood
Gerjon Hannink
Anke Lenting
Karlijn Groenen
Sander Koëter
Nico Verdonschot
Albert van Kampen

Publication: Am J Sports Med. 2015 Oct;43(10):2538-44.

ABSTRACT

Background: Reconstructing the medial patellofemoral ligament (MPFL) has become a key procedure for stabilizing the patella. Different techniques to reconstruct the MPFL have been described: static techniques in which the graft is fixed rigidly to the bone or dynamic techniques with soft tissue fixation. Static MPFL reconstructions are most commonly used. However, dynamic reconstructions deform more easily and presumably function more like the native MPFL.

Hypothesis/Purpose: The aim of the study was to evaluate the effect of the different MPFL fixation techniques on patellofemoral pressures compared to the native situation. We hypothesized that a dynamic reconstruction results in patellofemoral pressures closer to those generated in an intact knee.

Study Design: Controlled laboratory study.

Methods: Seven fresh frozen knee specimens were tested in an in-vitro knee joint loading apparatus. Tekscan® pressure sensitive films fixed to the retropatellar cartilage measured mean patellofemoral and peak pressures, contact area, and the location of the center of force (COF) at fixed flexion angles from 0-110 degrees. Four different conditions were tested: intact, dynamic, partial dynamic and a static MPFL reconstruction. Data were analyzed using linear mixed models.

Results: The static MPFL reconstruction resulted in higher peak and mean pressures from 60-110° of flexion ($p<0.01$). There were no differences in pressure between the two different dynamic reconstructions and the intact situation ($p>0.05$). The COF in the static reconstruction group moved more medially on the patella from 50-110° of flexion compared to the other conditions. The contact area showed no significant differences between the test conditions.

Conclusion: After a static MPFL reconstruction the patellofemoral pressures in flexion angles from 60-110° were three to five times higher than in the intact situation. The pressures after dynamic MPFL reconstructions were similar as compared to the intact situation and could therefore be a safer option to stabilize the patella than static reconstructions.

Clinical Relevance: This study showed that a static MPFL reconstruction results in higher patellofemoral pressures and thus enhances the chance of osteoarthritis on the long term, while a dynamic reconstruction results in more normal pressures.

Key Terms: MPFL reconstruction, patella, patellofemoral pressure, trochlea, medial patellofemoral ligament.

INTRODUCTION

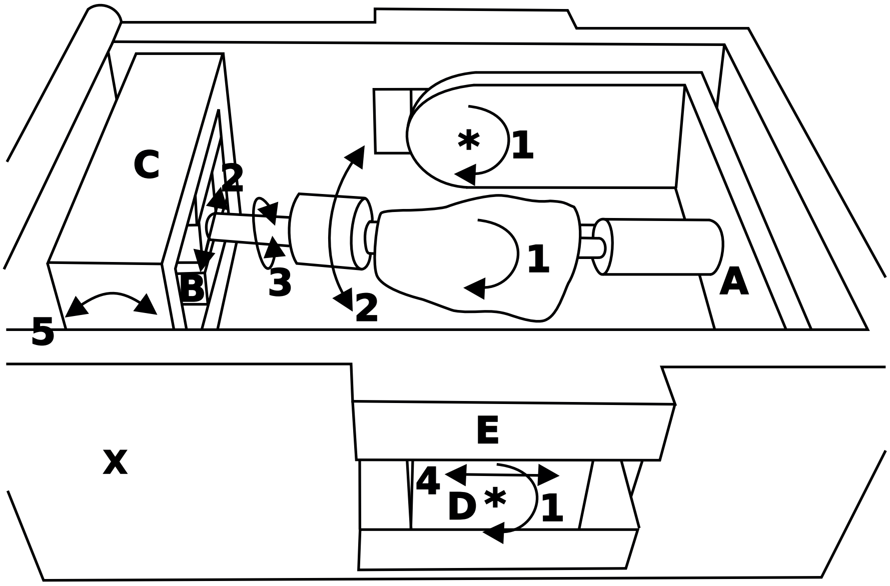
Patellofemoral instability is a common problem seen by knee surgeons.[4] The medial patellofemoral ligament (MPFL) is the main soft tissue stabilizer of the patella, and a lesion of this ligament is the major cause of symptomatic patellar instability.[13] The native MPFL originates from between the adductor tubercle and the medial epicondyle on the distal femur and has its insertion on the medial patella rim.[2, 6, 19, 26, 27, 32, 35, 38] The MPFL is responsible for more than 50% of the generated force to prevent lateralization of the patella between full extension and 30° of flexion.[13, 29] In case of a lateral patella dislocation the MPFL is damaged in 94-100% of the cases.[21]
In the last ten years, surgery to reconstruct this ligament has become more common, and various techniques and graft materials have been described.[8, 11, 36] A division into 2 main graft fixation categories can be made, i.e. static and dynamic MPFL reconstructions. In static reconstructions the ligament is attached to the bony structures using tunnels, screws and/or anchors. The exact anatomic point of the femoral attachment of the graft in this type of reconstruction is crucial and can be difficult to determine.[2, 33, 35, 38] In dynamic reconstructions the graft is not attached to the bone on the femoral side but to soft tissue. The graft is tunneled around the adductor tendon near its insertion on the medial femur condyle or passed through the medial retinaculum, both resulting in a less rigid reconstruction.
Static MPFL reconstructions with rigid tendon to bone fixation might result in higher patellofemoral pressures which may ultimately lead to patellofemoral osteoarthritis.[9, 14, 28, 37] In contrast, due to their soft tissue fixation dynamic reconstructions of the MPFL deform more easily and presumably function more like the native MPFL.

Although both static and dynamic reconstructions of the MPFL have already shown good short term results in terms of stability and functional outcome,[8, 11, 15, 18, 22] the risk of developing patellofemoral osteoarthritis on the long term remains unclear.[25] Patient outcomes after dynamic and static MPFL reconstruction procedures have been previously reported by Becher et al.[8] and Gomes.[20] They concluded that both techniques provided satisfactory short-term outcomes, and that even in the absence of significant differences, their results suggest that a dynamic femoral fixation is more advantageous than a rigid alternative.
The aim of our study was to evaluate the effect of static and dynamic MPFL reconstructions on patellofemoral pressures and to compare these with patellofemoral pressures in the native situation. We hypothesized that dynamic reconstructions result in patellofemoral pressures that are closer to the native situation.

MATERIALS AND METHODS

Seven fresh frozen human cadaveric knee specimens (4 left, 3 right; average age 79 (range 67-89); 4 male, 3 female) were tested in an in-vitro simulation using a knee loading apparatus (Fig 1).[7] The knee loading apparatus has been previously described in detail. CT-scans were made to exclude trochlear dysplasia, severe osteoarthritis or patella alta. All cadaveric knees were suitable for the experiment and included. To fit the specimens in the loading apparatus, each specimen was transected 210 mm proximal and distal to the joint line. The skin and subcutaneous fat were peeled off to obtain a proper exposure of the muscles. The sectioned ends of the bones were potted in bone cement to allow fixation into the loading apparatus. The tendon of the m. gracilis was stripped for use as a graft for the MPFL reconstruction later on.
The quadriceps muscles were separated into three groups: 1) the vastus lateralis (VL), 2) vastus medialis (VM), and 3) a central muscle group consisting of vastus intermedius (VI) and rectus femoris (RF; the VI was dissected from the femur and attached to the femoris rectus (FR) muscle). Aluminum strips were wrapped around the proximal end of each muscle group and attached by stitching through the muscle end to provide a strong, firm attachment for the muscle loading cables. A total load of 50N was applied to the 3 muscle groups, i.e. 1) 20N to the VL, 2) 12.5N to the VM, and 3) 17.5N to the FR+VI, according to the directions and physiological cross-sectional areas of the muscle described earlier.[16, 17, 39] A constant force of 20N was applied to the hamstrings.

Figure 1: Schematic drawing of the knee loading apparatus



*With this apparatus the knee flexion movement can be applied manually and the tibia and patella have freedom of motion to find their own orientation. Flexion (1) is achieved by manual rotation of bracket A around joint *. The tibia is free to move in varus and valgus (2), trough translation of block B in slot C. The tibia is also free to rotate internally and externally (3). Joint translations are allowed through translation 4 (block D/bracket A moving in slot E) and rotation 5 (rotation of block C around joint x).*

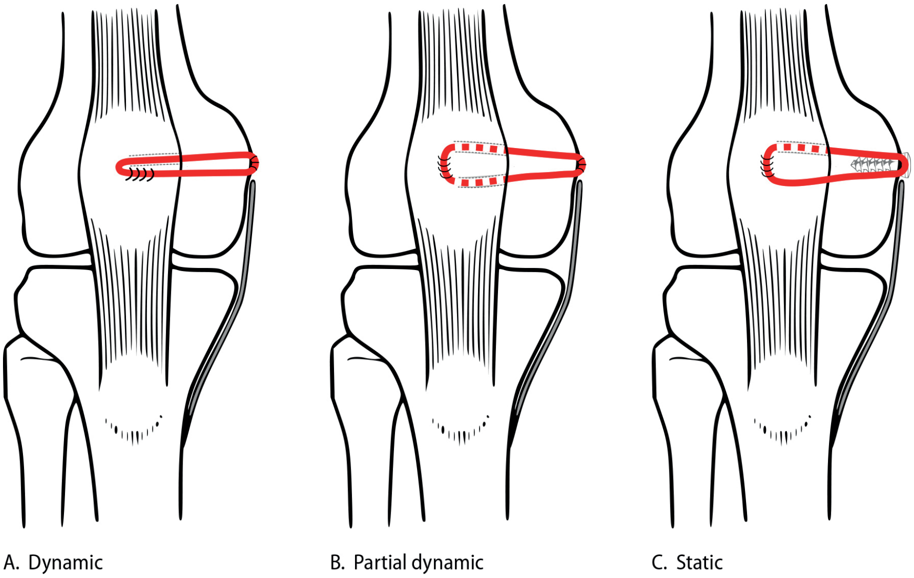
The knee joint was opened by a small medial arthrotomy of 3 cm. A pressure sensor (Tekscan 4205 pressure sensor, I-Scan, Boston, Massachusetts) was fixed to the retropatellar cartilage with skin glue (Dermabond®), covering the whole surface of the patella. To ensure fixation one suture was placed through the sensor handle and the surrounding tissue. The sensor allowed patellofemoral contact pressure and pressure localization to be measured dynamically. All sensors used in our experiment were conditioned, equilibrated and calibrated using a materials testing system (MMED, Materials Technology Corporation, La Canada, CA, USA) and a custom calibration tool consisting of two Teflon plates covered with rubber to mimic articular cartilage. The calibration curve was derived from a ten point polynomial fit through the calibration points that were equally distributed between the minimal and maximal expected pressure, i.e. 0 and 1.6 MPa.[10] Experiments were performed immediately after calibration of the sensors.

Mean and peak pressure, contact area, and the centre of force (as the geometric centre of the loaded pressure area) were calculated (Tekscan® software v6.03, Tekscan® Inc., Boston). After the sensor was fixed to the patella, the knee joint was closed using sutures. Subsequently, the knee was inserted into the knee loading apparatus.

The test sequence started with a preconditioning regime of two full flexion-extension cycles (0-110°) that were performed manually. The actual measurements were performed statically at the following flexion angles: 0-10-20-30-50-70-90-110-0°.The final measurement at 0° flexion was implemented to assess whether tissue fatigue had influenced our measurements during the flexion cycle. In each cadaveric knee the following 4 conditions were tested in the same order, 1) intact MPFL (intact), 2) a dynamic MPFL-reconstruction with soft tissue fixation only (dynamic), 3) a partial dynamic MPFL-reconstruction with soft tissue fixation on the femur and two bone tunnels in the patella (partial dynamic), and 4) static MPFL-reconstruction (static). In the dynamic reconstruction, the femoral attachment was at the location of the insertion of the adductor magnus tendon and the patellar fixation was with sutures to the periosteum and subcutaneous tissue as described by Chassaing et al.[12] and Arendt.[5] In short, along the medial side of the patella a medial arthrotomy of 4 cm was made, leaving the synovium intact. The plane between the synovial tissue and the medial retinaculum was bluntly opened towards the medial epicondyle. One centimeter distal and dorsal from the epicondyle an opening in the retinaculum was made by pushing the end of a clamp inside out trough the tissue. One centimeter proximal of this opening a second opening in the retinaculum was made. The graft was lead through the first opening outside the retinaculum, looped around the adductor tendon, and led back inside through the second opening in the retinaculum. Using a straight clamp, a subperiostal tunnel was made from the proximal 1/3rd of the medial border to the midline of the patella. One of the ends of the graft was pulled through this tunnel, flipped back and pulled towards the other end. After slight tensioning of the graft in 30° of knee flexion, the graft was sutured to the other end of the graft and to the periosteum. (Fig. 2A)

The partial dynamic reconstruction had the same femoral fixation but the graft was fixed to the patella through two 5 mm parallel patellar bone tunnels as previously described by Schöttle et al.34 (Fig. 2B). In the static reconstruction the same patellar bone tunnels were used but the femoral graft fixation was with a metal staple at the anatomic insertion on the femur,[2, 9, 24, 38] in 30 degrees of flexion (Fig. 2C). All knees were operated on while fixed in the loading apparatus by a senior orthopedic surgeon (AvK) with > 20 years of experience in surgery for patellofemoral instability.

Figure 2: Schematic illustration of the three different types of MPFL reconstructions



The three different methods of MPFL reconstruction used in our study: A. Dynamic, where the graft is attached to soft tissue only on the patellar and femoral side. B. Partial dynamic, where looping the graft through two bony tunnels in the patella altered the patellar attachment of the graft. C. Static, where the graft was fixed to the femur with a staple leaving the patellar attachment using the bony tunnels intact.

Statistical analysis

Linear mixed models were used to fit the individual profiles to a 3rd degree polynomial. The dependent variables were either the peak pressure, mean pressure, contact area or center of force in mediolateral direction. The independent class variable was the test condition (intact, full dynamic, partial dynamic, and static). Interaction terms between test condition and the regression variables were included in the model. The intercept and the regression coefficients of flexion were treated as random effects. In addition, condition-specific intercepts were added to the model. In this way, differences between individual profiles were optimal allowed. The differences between the models with random effects and higher or lower degree polynomials were tested using likelihood ratio tests.

Likelihood ratio tests showed that when polynomials were used with either a

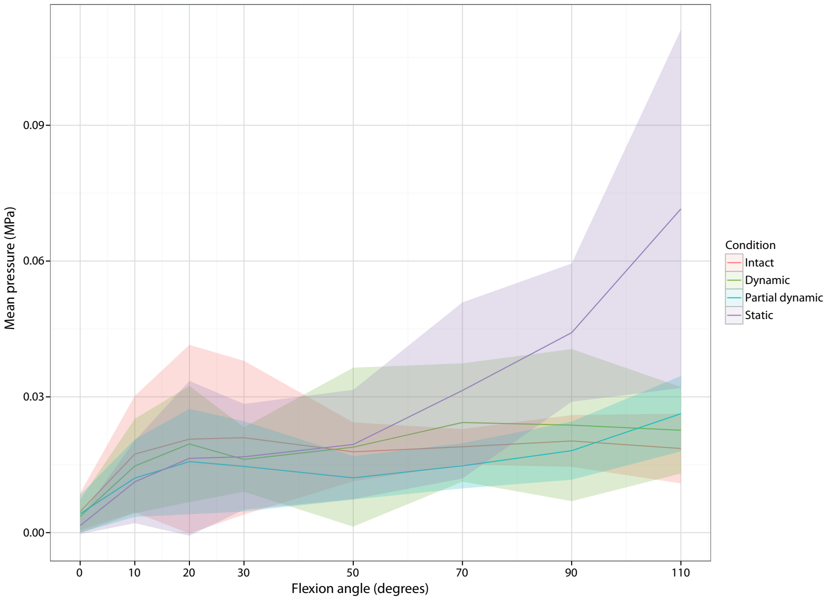
higher or lower degree than 2, the fit was statistically decreased. The estimated regression parameters with standard errors were used to calculate the mean pressure profiles with 95% confidence intervals for each test condition. Moreover, the differences of pressure profiles with 95% confidence intervals between test conditions were calculated.
Estimated mean differences with 95% confidence bands of peak pressure, mean pressure, contact area, and center of force, respectively, were calculated between the following test conditions using the linear mixed models: 1) intact versus dynamic; 2) intact versus partial dynamic 1; 3) intact versus static; 4) dynamic versus partial dynamic; 5) dynamic versus static; and 6) partial dynamic versus static. Multiple comparisons were accounted for with Tukey's correction. The statistical analysis were performed using R version 3.0.2 with package 'nlme'.[30, 31]

RESULTS

Mean patellofemoral pressure

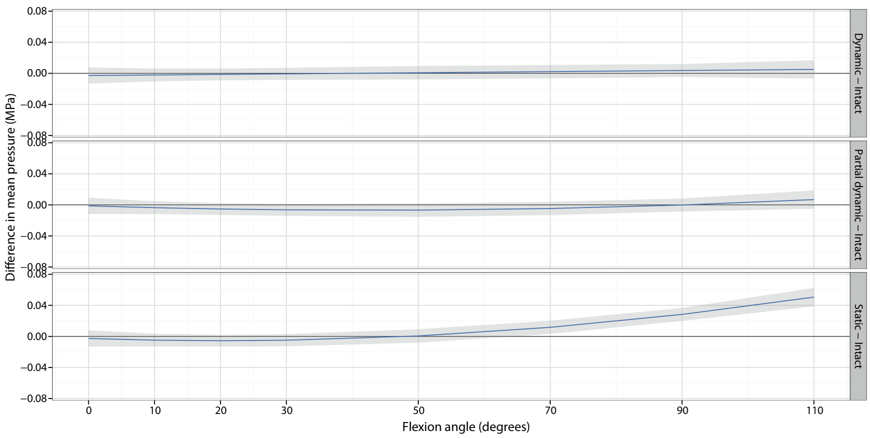
In all conditions the mean patellofemoral pressure increased with an increase in flexion angle. The mean patellofemoral pressures in the partial and dynamic reconstruction during the flexion cycle were comparable with the intact situation, that is, mean patellofemoral pressures only slightly increased over the flexion trajectory. There were no differences in mean patellofemoral pressures between the dynamic reconstructions and the intact situation ($p>0.05$). However, in the static reconstruction the mean patellofemoral pressures started to increase strongly from approximately 60° with the highest pressure at the end of the flexion cycle at 110° flexion (Fig 3). At the end of flexion cycle the mean pressure was more than 5 times higher compared to the intact situation (resp. 0.072 MPa vs. 0.019 MPa, (difference 0.053 MPa (SE 0.0061 MPa); $p<0.001$)) (Fig 4).

Figure 3: Mean pressure



Mean pressure profiles with 95%CIs in each of the four conditions. In all conditions the mean pressure rises slightly when flexion progresses. In the static condition, mean pressure rises remarkably higher at the end of the flexion cycle.

Figure 4: Mean pressure of the dynamic, partial dynamic and static conditions compared to the intact situation



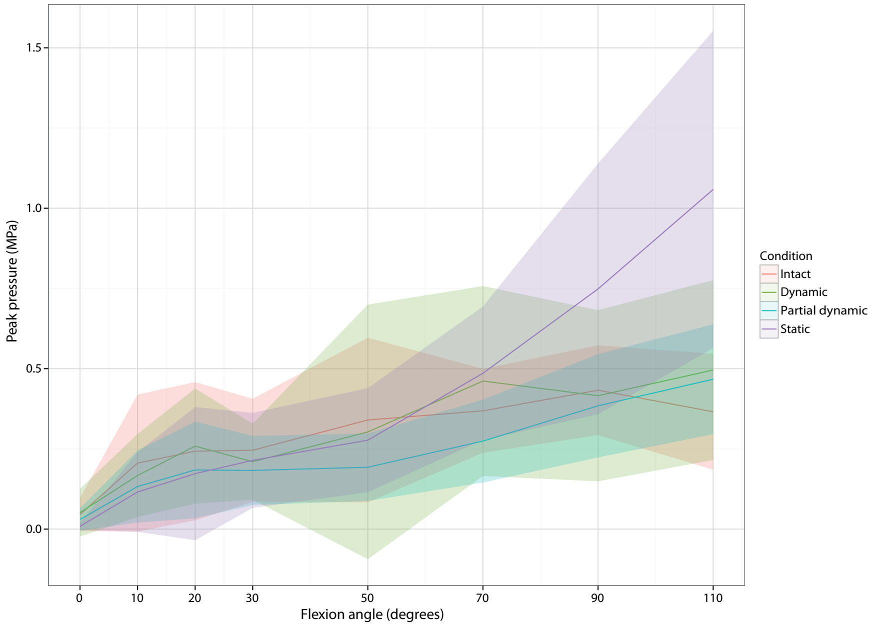
4

Differences in mean pressures with 95%CIs between the intact versus dynamic, partial dynamic and the static MPFL reconstruction. The horizontal line with intercept 0 represents no difference between conditions. The dynamic conditions have comparable mean pressures during the whole flexion cycle compared to the intact situation. The static reconstruction leads to significantly higher mean pressures from 70-110° of flexion.

Patellofemoral peak pressure

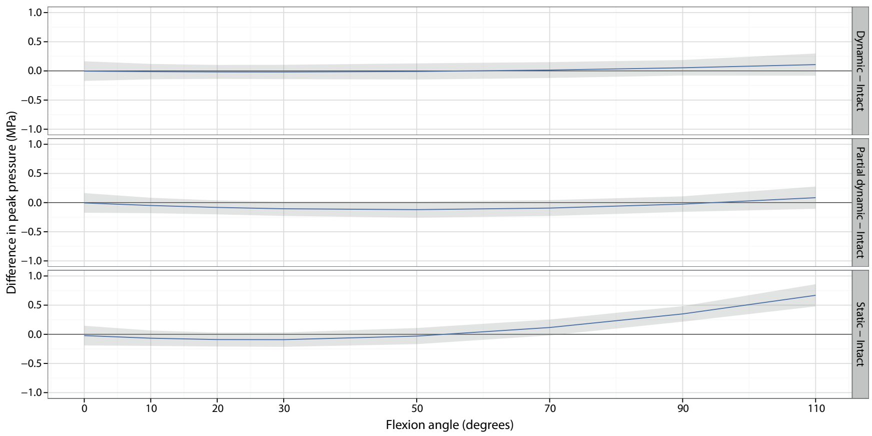
The peak pressure in the intact situation was low (0.01 MPa) in full extension and progressed to a maximum of 0.43 MPa at 90° of flexion. No differences were found comparing the intact and the two dynamic MPFL reconstructions (Fig 5). However, in the static reconstruction the peak pressures differed from the intact situation from 80-110° of flexion, where at a flexion angle of 110° the peak pressure was almost three times as high (resp. 0.39 MPa vs. 1.06 MPa, (difference 0.67 MPa (SE 0.096 MPa); $p<0.001$)) (Fig 6).

Figure 5: Peak pressure



Peak pressure profiles with 95%CIs in each of the four conditions. The peak pressure elevates in all conditions when flexion progresses, with a maximum *at 90° of flexion in the intact condition. The dynamic conditions resemble the native situation, while the peak pressures in the static condition from 70 to 110 degrees are much higher.*

Figure 6: Peak pressure of the dynamic, partial dynamic and static conditions compared to the intact situation



Differences in peak pressures with 95%CIs between the intact versus dynamic, partial dynamic and the static MPFL reconstruction. The horizontal line with intercept 0 represents no difference between conditions. Comparing the peak pressure in the two dynamic conditions to the intact situation shows no differences. The peak pressures in the static reconstruction are remarkably higher at 90-110° compared to the intact situation.

Patellofemoral contact area

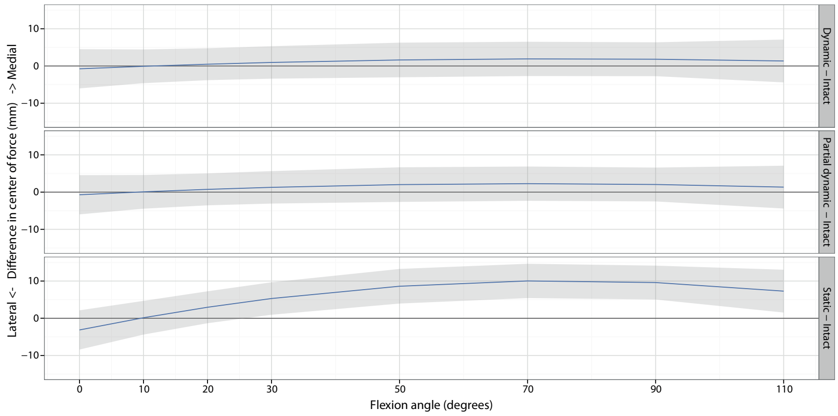
In all conditions the contact area increased strongly during the first sixty degrees of flexion, after which the contact area increased more slowly reaching the largest contact area at 90 degrees of flexion. From 90-110° of flexion, the contact area decreased again. No differences in contact area between the test conditions were found.

Centre of force (COF)

The proximal-distal movement of the COF was comparable in all conditions: the COF started distal on the patella in extension and moved proximally when flexion progresses, reaching the most proximal point at 90 degrees of flexion.

In the mediolateral direction the center of force moved from lateral to medial during the flexion cycle in all conditions. In the intact and dynamic condition, this was only a small medial movement central on the patella (4.40mm (SE 2.75mm) and 4.63mm (SE 2.30mm), respectively) (Fig 7). In the partial dynamic group the medial translation was slightly more, but not statistically different from the intact and dynamic conditions. The overall mediolateral translation of the COF was more than twice as high in the static reconstruction group (11mm (SE 3.27mm)) compared with the intact situation (4.63mm (SE 2.30mm)). The most substantial difference in COF between these conditions was found at 70° of flexion, where the COF was located 5.27 mm (SE 1.37 mm; p <0.001) more medial in the static condition. (Fig 7)

Figure 7: Mediolateral translation of the location of Centre Of Force of the dynamic, partial dynamic and static conditions compared to the intact situation



Differences of the location of the center of force profiles with 95%CIs between the intact versus dynamic, partial dynamic and the static MPFL reconstruction. The horizontal line with intercept 0 represents no difference between conditions. In the partial dynamic and the dynamic conditions, the translation of the COF is comparable to the intact situation. In the static condition, the COF started at a more lateral position than in the other conditions at full extension (although not statistically different), moves only medially when flexion progresses and ends far more medial compared to the intact situation.

DISCUSSION

In this study we evaluated the effect of static and dynamic MPFL reconstructions on patellofemoral pressures and compared these with pressures in the native situation. We found that static MPFL reconstructions cause higher patellofemoral pressures, with three to five times higher pressures in flexion angles from 70-110°. After dynamic MPFL reconstructions, both mean and peak patellofemoral pressures were similar to those in the intact knee. The most likely explanation for these higher pressures in static reconstructions is that the reconstructed ligament cannot be completely isometric and tightens in flexion. Abnormal high patellofemoral pressures are an important factor in the development of degenerative joint disease, especially when combined with repetitive trauma, and hemarthroses.[4] Recurrent patellar dislocations provides all of the afore mentioned factors, and in our view patella stabilization should be aimed at normalizing the intra-articular biomechanics in order to diminish the already higher chance of developing osteoarthritis.
No differences in terms of patellofemoral pressures, contact area or mediolateral displacement were found between the partial and dynamic reconstruction methods in this study. The only difference between the two dynamic reconstructions was the fixation on the patella. Using tunnels resulted in a "v"-shaped ligament being more similar to the native situation.[2, 24] However, a benefit of a reconstruction without any bone anchorage is the elimination of the risk of a patella fracture. Another advantage is that the procedure is less expensive since no additional hardware has to be used.

The results of the patellofemoral pressure measurements in our study were similar to those earlier described in literature, showing a increase of the pressure with increasing flexion of the knee.[9, 26, 28] The movement of the center of force was also comparable to other studies.[14, 29, 37] The rise in both mean and peak pressure after a static MPFL reconstruction in more than 60 degrees of flexion was also found by Stephen et al.[37] after a static MPFL reconstruction. They did not study dynamic reconstructions and concluded that graft overtensioning or malpositioning (either too proximal or too distal) of femoral tunnels, caused the significantly elevated medial joint contact pressures.
This study is not without limitations. Our experimental design was a simplified representation of the situation in vivo. Limitations of this study include those inherent to in vitro testing. The cadaveric knees were from elderly donors and with normal patellofemoral geometry, and it is unknown how these extrapolate to those with patella alta, trochlea dysplasia and MPFL lesions. The forces

applied on the quadriceps and hamstring muscles were based on a model of the real muscle force in vivo and do not replicate the dynamic adjustments of the muscles during a flexion cycle in vivo.[16, 17, 39]. Although the quadriceps forces used in our study were lower than the forces used in previous studies,[9, 28] patellofemoral movements have been shown to be reproducible with lower quadriceps forces. However, it has been shown to be important that the forces are distributed proportionally to these tendons.[39] The distribution of forces was calculated according to the directions and physiological cross-sectional areas of the muscle as described earlier.[16, 17]
In addition, the iliotibial band has been shown to influence patellar tracking, but so does the whole thigh-muscle complex. In this cadaver set-up the focus was on the relative constraints generated by the various MPFL reconstruction techniques, rather than on the precise consequences. Therefore no load was applied to the iliotibial band.
The Tekscan sensor was inserted proximally, however, to make sure that the sensor was not able to move during the different conditions the sensor had to be glued to the patella so a small arthrotomy was necessary. Because of the need for a medial arthrotomy to perform the MPFL reconstructions this was the favorable side.
In a pilot study we evaluated the influence of sensor and medial arthrotomy on patellofemoral kinematics using Fastrak (3SPACE Fastrak, Polhemus, Colchester, VT) (unpublished data) and found that the influence of both sensor placement and medial arthromtomy on patellofemoral kinematics was negligible. (See online supplement)
Some potential limitations of the Tekscan sensors also have to be discussed. The durability and repeatability of Tekscan sensors have been shown to be considerably restricted in the presence of shear forces,[40] sensitive to temperature and the presence of fluids,[23] and should be sterilized before calibrating as sterilization causes decalibration.1 However, Wilharm et al.[40] recently studied the use of Tekscan sensors for retropatellar pressure measurements and showed that retropatellar pressures can be reliably measured using these sensors. They studied the effect of insertion approaches, and recorded and quantified possible sensor fatigue in 10 human cadaver knee specimens. It was concluded that measurement accuracy relies on the secure attachment of the sensor to the retropatellar joint surface and that all measured parameters are useless when the sensor position shifts during the test. Previously, it has been reported that the results of complete tests could not be evaluated because of shifts in sensor position.[3] By gluing the sensor to the patellar cartilage in combination with sutures we ensure secured attachment of

the sensor in our experiment.
The repeated measures design chosen for this study can both be seen as a strength and a limitation. Investigating the different MPFL reconstructions in the same knee allows a controlled comparison between the conditions. In all knees the different reconstructions were performed in the same order, from less invasive to more invasive methods. In this way, the knee was damaged as little as possible during the tests, and the same fixation points on the patella and femur could be used. This provides for better comparability of the four different test situations, because in effect most of the reconstruction is the same (the knee anatomy, the gracilis autograft, the location and orientation of the bone tunnels, etc.). The femoral fixation site is critical for an adequate reconstruction. In literature both an isometric fixation point, as an anatomical attachment have been described.[2, 6, 19, 24, 26, 32, 35, 38] We used the anatomic attachment that was previously described by Amis et al.,[2] and aimed to locate it carefully in all specimens. There is a chance that the identified anatomic insertion was slightly different from the true anatomic position, however, this variation reflects daily practice. Higher peak pressures, even in lower flexion angles (starting at 60 till 110 degrees of flexion), were measured in all static specimens and in none of the dynamic reconstructions or native knees. The soft tissue to which the graft was attached in the dynamic reconstructions is probably more compliant (i.e. can give way) when the tension on the graft increases, resulting in more deformation and lower patellofemoral pressures.

CONCLUSION

The present study showed that a dynamic reconstruction of the MPFL results in a pressure pattern that resembled the native situation in patellofemoral joint. In contrast, a static MPFL reconstruction resulted in three to five times higher patellofemoral pressures in flexion angles from 60 to 110 degrees. This implies that the dynamic reconstructions result in a more physiological patellofemoral joint loading, which may reduce the risk of developing patellofemoral osteoarthritis without compromising stability.[8, 20] Therefore, the dynamic MPFL reconstructions could be a safer option when stabilizing the patella.

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CHAPTER 5

Complications of a Medial Patellofemoral Ligament Reconstruction Using Two Transverse Patellar Tunnels

Loes Schiphouwer
Akkie Rood
Siebren Tigchelaar
Sander Koëter

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Publication: Knee Surg Sports Traumatol Arthrosc. 2017 Jan;25(1):245-250.

ABSTRACT

Purpose: The aim of this study was to report complication rates of a medial patellofemoral ligament (MPFL) reconstruction using transverse patellar tunnels in a retrospective case series performed in a single institution.

Methods: Case series of 179 patients (192 knees) that had an MPFL reconstruction, with or without additional bony realignment procedures, between January 2009 and March 2015. Data was obtained from available patient charts.

Results: Thirty-nine complications (20.3%) were registered. Twenty-seven of these (14.7%) were minor. Seven patients (3.6%) sustained a patellar fracture without adequate trauma. Male gender was a risk factor for patellar fracture ($p<0.001$). Sixteen (8.1%) reported recurrence of instability, of whom 10 (5.1%) were defined as objective instability (reported dislocation and positive apprehension test).

Conclusion: This is largest patient series to date in whichthe complications after a two tunnel MPFL reconstruction are described. The use of transverse patellar tunnels increases the risk of sustaining a patellar fracture.

Level of evidence: Level IV

Keywords: Medial patellofemoral ligament, MPFL, patellar instability, MPFL reconstruction, complications

INTRODUCTION

The medial patellofemoral ligament (MPFL) is a soft tissue restraint to lateral dislocation of the patella.[1,23] It is nearly always disrupted after an initial dislocation.[9,22] After sustaining a primary dislocation, the risk of recurrence is relatively high. Reported percentages differ greatly, but approximately half of all patients have recurrent dislocations.[8,17,29] In case of persistent instability surgical management is the best option.[29] There are several anatomical factors associated with instability.[30] Surgery is aimed at addressing these abnormalities. Soft tissue repair techniques have been introduced two decades ago. These soft tissue approaches seem to be safer than the osseous techniques, which were the keystone of patellar stabilization in the previous decades.
Since the introduction of MPFL reconstruction, numerous techniques have been described. All techniques employ fixation of a graft to the femur and the patella with sutures, bone tunnels or anchors. Overall results have been favorable so far in terms of functional outcome and recurrence of instability.[19,28,31] As with all new techniques the early success of the procedure has outshone the potential risks of the procedure. Post-operative complications are rarely reported and the use of different definitions of complications, heterogeneity in surgical techniques and small sample sizes make it practically impossible to give a realistic comparison between studies and techniques.
The incidence of reported complication is highly variable and ranges from 3%-85%[7,12,25,27], ranging from wound infections to patellar fractures. A large systematic review on complications of MPFL reconstructions by Shah et al.[27] reported a mean complication rate of 26% ± 21% among included studies. Overall recurrence of dislocations and subluxations was 3.7%; there was significant post-operative pain in 5.4% and patellar fractures occurred in studies using tunnel fixation in 0.9%. However, these numbers are mere averages and do not represent the complication rates of specific surgical techniques. Large studies reporting complication rates of specific surgical techniques are needed to give a clearer view on this. These studies can help determine what the safest technique is.

This retrospective study reports the complications and recurrence rates of patellofemoral instability in a large group of patients after an MPFL reconstruction using two transverse patellar tunnels performed in a single institution. The aim of this study was to give a clear view of the complication rates of this technique.

MATERIALS AND METHODS

Data collection

All patients who were operated between January 2009 and March 2015 for recurrent patellar dislocations using a double bundle dynamic MPFL reconstruction were included. Patient charts were reviewed for data collection. If the procedure was not complicated, patients were asked to visit the outpatient clinic at 6 weeks and 6 months post-operatively.

Patients

One hundred and ninety-two knees in 171 patients with persistent patellar instability were included. Patellar instability was defined as a history of multiple patellar dislocations as reported by the patient and the presence of a hypermobile patella with a positive apprehension test on physical examination. The indications for MPFL surgery were recurrence (2 or more episodes) of patellar instability after failure of conservative management or a first-time patellar dislocation with a concurrent osteochondral fracture. All procedures were performed by one of the two authors (ST, SK) using similar surgical technique. If needed, the MPFL reconstruction was combined with other procedures such as a tibial tubercle transfer or a trochlea osteotomy.

The median age at operation was 19 years (range 10 - 57 years) and 129 of the knees were female (67.2%). Twenty patients had a history of previous unsuccessful surgery to stabilize the patella. Sixteen of these knees previously underwent a distal realignment procedure and four knees a soft tissue procedure, such as medial reefing or a lateral release. Preoperatively, patellar height, the degree of trochlear dysplasia, lateralization of the tibial tubercle and patellar tilt were assessed using lateral X-rays and CT or MRI scans. In case of the presence of a patella alta (Caton-Deschamps index >1.2) or a lateralized tubercle (TT-TG distance >15mm) a tibial tubercle osteotomy (TTO) was performed concurrent with the MPFL reconstruction. In patients with severe trochlear dysplasia, the need for a trochleoplasty (TP) was assessed intraoperatively, based on the presence of a bump and degree of instability. An overview of which procedures each patient had and their surgical history is listed in table 1. One hundred and fifty-six out of the 197 knees (81.3%) had at least one additional procedure to the MPFL reconstruction. In 134 knees (69.8%) an additional TTO was performed; 2 knees (1.0%) underwent an additional TP and in 21 knees (10.9%) both procedures were performed. Nine patients had open epiphyseal plates and did not undergo any additional procedures, despite the presence of a patella alta or lateralized tibial tubercle in six of these patients. In one patient with a previous open lateral release, the lateral retinaculum was closed in addition to the MPFL reconstruction and TTO.

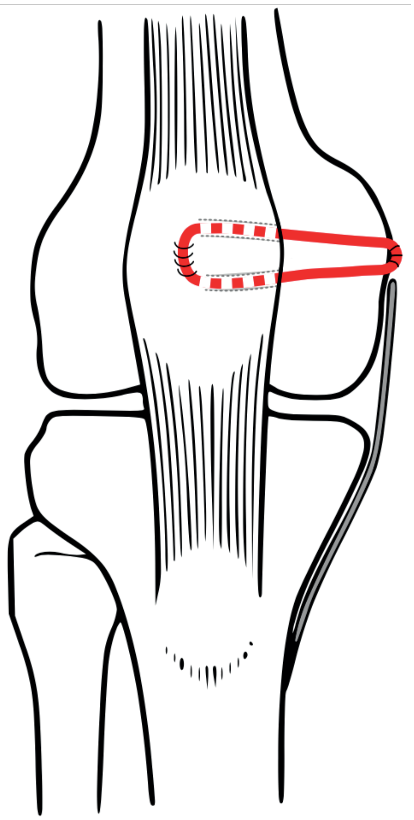
Table 1: Overview of performed procedures and surgical history.

	N	%
Isolated MPFL	35	18,2%
Previous surgical history	6 (previous TTO)	
Additional TTO	134	69,8%
Previous surgical history	9 (6 previous TTO, 3 medial reefing)	
Additional TTO and TP	2	1,0%
Previous surgical history	2 (previous TTO)	
Additional TP	21	10,9%
Previous surgical history	3 (2 previous TTO, 1 medial reefing)	

Surgical technique

The MPFL was reconstructed using a hamstring autograft, preferably the gracilis. The graft was harvested from the ipsilateral knee using an incision over the tibial tubercle. For fixation to the patella and the femur, two small separate incisions were used, one at the medial border of the patella and one at the medial femoral epicondyle. First, the adductor tubercle was located on the femoral condyle. The graft was looped around the tendon and the two free ends were passed under the superficial retinaculum. The graft was passed between layer 2 (medial retinaculum) and layer 3 (capsule) on the medial side of the knee. Using a 4.5mm endobutton drill, two transverse tunnels were drilled from the medial border of the patella to the anterior patella cortex. The free ends of the graft were passed through the tunnels and attached to the patella using absorbable sutures. The isometry of the graft was determined through a complete range of motion. After temporary fixation, a maximum of 5 mm of length change with flexion-extension of the knee was achieved (see Fig. 1). In patients with a lateralized tubercle or a patella alta, a TTO was performed prior to the MPFL reconstruction, using the same incision that was used for harvesting the graft. The osteotomy was fixed using two small fragment compression screws. The technique and results for this procedure have been described previously.[15,32] In patients with severe trochlear dysplasia, where an MPFL reconstruction and TTO would be insufficient, a TP was performed. A midline incision was used at the patella instead of the medial incision. The lateral retinaculum was opened with a z-shaped incision and the shape of the trochlea was assessed. In case of a trochlear bump without significant cartilage damage, the proximal cartilage was liberated from the subchondral bone and a bur was used to deepen the trochlea. The cartilage was reattached to the trochlea using absorbable sutures on the proximal edge. If the lateral side of the trochlea was insufficient, an anterior lateral open wedge osteotomy was performed. The opening was filled with a small bone block that was harvested from either the tibial tubercle or the iliac crest. This technique and its results have also been described previously.[16] All patients followed the same rehabilitation protocol: full weight bearing in a removable Velcro or cast splint and a maximum of 90 degrees of flexion for six weeks.

Figure 1: Schematic drawing of MPFL reconstruction. The graft was looped around the adductor tendon, the free ends of the graft were passed between the retinaculum and capsular layer, and then separately passed through either one of the patellar tunnels and sutured to the periosteum.



Data analysis

Both objectives as subjective instability were included in the results, with objective instability defined as a reported episode of instability and the presence of a hypermobile patella and/or a positive apprehension test on physical examination. The complications were stratified into patients undergoing an isolated MPFL reconstruction and patients undergoing an MPFL reconstruction with additional procedures. All complications were categorized as either minor or major. Minor complications include events that are unlikely to have influenced the functional outcome or caused no permanent harm to the patient. Complications were classified as major if they affected outcome or required re-operation. Complications that were specific for the TTO (such as irritation of the screws used for fixation of the osteotomy) were not included in the results.

Statistical analysis

An independent sample t test was used to compare the age of the group with and the group without complications. A Fisher's exact test was used to detect significant differences in prevalence of complications between the following subgroups: male versus female, isolated MPFL versus combined procedures and skeletally mature versus skeletally immature patients. This test was repeated for every individual complication as well. For all datasets, differences with p values < 0.05 were considered statistically significant.

RESULTS

Patients were routinely followed up at 6 weeks and at 6 months post-operatively. Thirty-three patients did not come to the clinic at 6 months and had a shorter follow-up. One hundred and thirty-three patients had a follow up of more than 6 months. Median follow-up was 9 months (range 1 - 67 months). Most common reasons for longer follow-up were: recurrent instability, post-operative complications, consultation for contralateral knee issues and request for TTO hardware removal. Out of the 192 operated knees, 39 knees had a registered complication (20.3%) (Table 2). Of these complications 12 were considered minor (6.3%) and 27 major (14.1%). Two patients had complications in both knees.

The patients in the complication group were younger than the patients without a complication (2.4 years, 95% confidence interval (CI) -4.52 to -0.24, p=0.029). There were no significant differences in age for the separate complications. There was no difference in recurrence of instability between male and female patients (p=0.59).

Table 2: Occurrence and demographics of complications

	Total (%)	**N female** (range)	**Median age after surgery** (range)	**Median time** (%)	**Isolated MPFL** additional procedures (%)	**MPFL** with
Complications	39/192 (20,3%)	21/39 (53,8%)	19 (9-42)	8 (2-41)	9/35 (25,7%)	30/157 (19%)
Minor	12 (6,3%)	5	20 (15-24)	N.A.	0 (0%)	12 (7,6%)
Wound infection	11 (5,7%)	5	19 (15-24)	N.A.	0 (0%)	11 (7,0%)
Wound dehiscence	1 (0,5%)	0	24 (N.A.)	N.A.	0 (0%)	1 (0,6%)
Major	27 (14,1%)	16	18 (9-42)	8 (2-41)	9 (25,7%)	18 (11,5%)
Recurrent instability						
Objective	10 (5,2%)	8	16 (9-42)	9 (3-41)	6 (17,1%)	4 (2,5%)
Subjective	6 (3,1%)	4	19 (14-24)	12 (4-27)	1 (2,9%)	5 (3,2%)
Pain	2 (1,0%)	2	18 (N.A.)	20 (N.A.)	0 (0%)	2 (1,3%)
Patellar fracture	7 (3,6%)	0	19 (15-26)	4 (2-13)	2 (5,7%)	5 (3,2%)
Flexion deficit	1 (0,5%)	1	28 (N.A.)	N.A.	0 (0%)	1 (0,6%)
Medical instability	1 (0,5%)	1	18 (N.A.)	4 (N.A.)	0 (0%)	1 (0,6%)

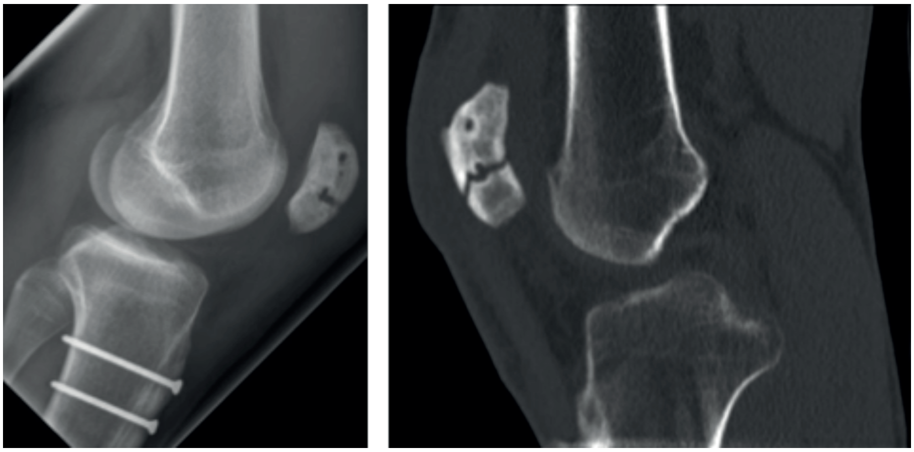
Major complications

Twenty-six major complications were reported. Six patients sustained a patellar fracture, one of them in both knees. Figure 2 shows the x-ray and an image for the CT scan of one of the patients. All patients were male; mean age was 20 years (range 15-27). Mean time of occurrence after surgery was 5.8 months (SD 4.3). There was no significant difference in occurrence between the isolated and combined procedure group. Male patients had a significant higher risk of sustaining a patellar fracture ($p < 0.001$).

Ten patients (5.2%) had objective recurrence of instability, of whom 6 in the isolated MPFL group (17.1%). In patients with open epiphyseal plates, the recurrence was 33.3% (3 out of 9), which was significantly higher than the recurrence in patients with skeletal maturity (33.3% versus 3.8%, $p < 0.01$). There was no significant difference in recurrence between the isolated MPFL and combined group.
Six patients (3.1%) had subjective recurrence of instability. There was no difference in subjective recurrence between the isolated and combined group. Other major complications were reported only once: a medial dislocation after failure of a repair of the lateral retinaculum concurrent with the MPFL reconstruction, a locally painful graft in both knees, laxity of the graft without

instability and a post-operative flexion deficit of 60°.

Figure 2: X-ray and image from a CT scan of a patient with a stable patellar fracture.



Minor complications

There were 12 complications related to the surgical wound: 11 wound infections and 1 dehiscence. All these complications occurred in the group with combined procedures.

DISCUSSION

The most important finding of the present study was the high prevalence of post-operative patellar fractures, which occurred in 3.6% of patients, usually within 1 year after surgery. All fractures occurred in male patients (7.5% of all male patients). The results in terms of stability were good, with a recurrence of objective instability in only 5.1%. Recurrence rate in patients with open epiphyseal plates was high (3 out of 9, 33%). Patients in the complication group were younger on average, but although this difference is statistically significant, it is small and probably not clinically relevant.

A patellar fracture is a major complication. This complication has been frequently reported.[2,6,10,11,13,14,18,20,21,24,25] The available studies are too heterogeneous and small to determine a reliable prevalence of patellar fractures. An association with tunnels placed too anteriorly, and thus weakening the anterior cortex of the patella has been mentioned.[4,11,25] The use of two transverse tunnels gives a higher risk, but fractures have also been reported in studies using only one tunnel or sockets.[2,5,11,18,20] A study on the complications of a similar technique to the one used in this study, employing two transverse patellar tunnels, in patients under 21 years (n=179) reported 6 patellar fractures, only two of whom were male.[25] This contradicts our finding of male gender being a risk factor for patellar fractures. Other studies were too small to determine the influence of gender. The time between the MPFL reconstruction and patellar fractures was similar in other studies, mostly occurring within 1 year.[3,5,14,18,21,24,25]

Most MPFL techniques employ a static fixation with an interference screw at the femur; the technique in this study reports the results of the adductor sling technique. A cadaver study by Rood et al.26 on patellofemoral pressures in different MPFL reconstructions shows that there is no increased contact pressure after the adductor sling technique, as we used in this study, while the pressure increases 3-5 times in the static technique from 60-110 degrees of flexion. This implies that the femoral fixation used in this study has no negative influence on the risk of patellar fractures, i.e. overloading the patellar attachment.

Recurrence of instability in this group was similar to other studies.[19,27] It should be noted that the recurrence in this group cannot be solely attributed to the MPFL reconstruction, since more than 80% of patients underwent an combined procedure, and it was impossible to determine the exact reason of failure retrospectively.

The major strength of this study is the large sample size. Patellofemoral instability is a relatively uncommon disorder and most other single center studies have a much smaller population than the one we reported here, with an average sample size of about 30.[19,27] The main limitation of this study is its retrospective nature, using only available patient charts, and the spread in follow-up. Recurrent instability occurred on average after 17 months, so it is possible that the recurrence instability is underreported in this study. The majority of patients (81.3%) underwent additional procedures to the MPFL reconstruction, and complication rates in an isolated MPFL reconstruction can be different.
It is possible that (minor) complications are underreported.

CONCLUSION

This is largest patient series to date in which the complications after a two-tunnel MPFL reconstruction are described. The surgical technique that was used in this study gives an unacceptable high risk of patellar fractures due to the use of transverse patellar tunnels. Alternative patellar fixation methods should be considered. More comparative research is needed to determine which fixation method gives the best functional results and the lowest complication rates.

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CHAPTER 6

Good clinical results after a new dynamic Medial Patellofemoral Ligament Reconstruction In Skeletally Immature Patients.

Geerte S. Olthuis
Akkie Rood
Sander Koëter
Sebastiaan A.W. van de Groes

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Submitted to: Journal of Pediatric Orthopaedics

ABSTRACT

Purpose: Patellar dislocation in children has an exceptionally high recurrence risk. A treatment to restore the patellar stability in skeletally immature patients is a dynamic reconstruction of the medial patellofemoral ligament (MPFL). To date, only a few studies investigated the clinical outcomes after MPFL reconstructions in skeletally immature patients. This study evaluates the persistence of instability, the complication rate, and the subjective clinical outcome after mean of 4 years.

Methods: This retrospective cohort study included skeletally immature patients with open physis who received an isolated dynamic MPFL reconstruction. For the reconstruction, a gracilis tendon graft was looped around the adductor tendon, led through the retinaculum, and fixed to the patella with two transverse patellar bone tunnels. Preoperative patellar height, tibial tubercle to trochlear groove (TT-TG) distance and the degree of trochlear dysplasia were determined. Primary outcome was recurrence of instability; secondary outcomes were complications, the need of additional surgeries, and subjective clinical outcomes.

Results: Twelve skeletally immature patients (fifteen knees) were included. Mean patellar height according to Caton Deschamps was 1.3, the mean TT-TG distance was 21.6 mm, and 46.7% had severe trochlear dysplasia. Postoperative patellar instability rate was 26.7%, the complication rate was 13.3%, and 33.3% needed a reoperation. The mean postoperative Kujala score was 80.1 points.

Conclusions: The technique has an acceptable rate of recurrent instability. Although the technique is save, the patellar bone tunnels cause the most severe complication, which in the future should be avoided.

Keywords: Medial patellofemoral ligament, MPFL, dynamic reconstruction, immature patients, recurrent patellar instability

INTRODUCTION

Patellar dislocation in children has an exceptionally high recurrence risk: 44,8% in skeletally immature patients[20] and even higher (60%) in patients under 14 years.[11] Trochlea dysplasia is one of the risk factors for recurrence[15]. The management of recurrent instability in skeletally immature patients is challenging, and differs from the management in mature patients. Trochlea osteotomy or tibial tubercle transfer, alternative treatment options in mature patients, is contraindicated in skeletally immature because it will harm the open physis and result in growth disorders. A well-described technique to treat skeletally immature patients is a medial patellofemoral ligament (MPFL) reconstruction. In almost every case of lateral patellar dislocation, the MPFL is damaged.3,12 Several techniques describe the reconstruction of the MPFL.[1,2,6,7,14,16,17,25] These techniques can be divided into two groups; the static, and dynamic MPFL reconstructions. In the static technique, there is a fixed femoral attachment of the graft at the isometric point on the medial femoral condyle with screws or anchors. In the dynamic reconstructions, the graft is attached to soft tissue, for example by looping it around the adductor tendon. In the static reconstruction, the location of the femoral fixation is crucial to prevent over tightening, throughout the whole range of motion of the knee. Over tightening of the graft results in increased patellofemoral pressures, which may cause patellofemoral osteoarthritis in the long term.[9,19] In skeletally immature patients, it is important to avoid involvement of the physis.[23] It is challenging to find the right position, because the anatomic insertion of the MPFL is very close to the distal femoral physis[10]; incorrect placement of the fixation can cause severe complications.[18] In skeletally immature patients, a dynamic reconstruction is probably a safer procedure, since bone fixation is not needed at the femoral site.

The MPFL reconstruction can bridge the time until the physis closes, after which additional bony procedures can be performed if needed. Several studies even suppose that early stabilisation of the patella may have positive effects with respect to the patellofemoral joint. Normal tracking of the patella could help the development of the trochlea.[4,24] Benoit et al[4] concluded that adding intrinsic patellofemoral stability might remodel the trochlea. To date, there are only a few studies that have investigated the clinical outcomes after MPFL reconstructions in skeletally immature patients.[1,7,14,16,17,25] And there is only one study, which investigated the dynamic reconstruction in a study group larger than 7 patients. In this study we evaluated the persistence of instability (defined as at least one recurrent dislocation or subluxation), the complication rate,

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and the subjective clinical outcomes after a dynamic MPFL reconstruction in skeletally immature patients with a mean follow up of 4 years.

METHODS

Data collection

This retrospective cohort study included all skeletally immature patients with open physis who underwent an isolated MPFL reconstruction in the CWZ (Canisius Wilhelmina Hospital), in Nijmegen, in the Netherlands. The patients were operated between January 2009 and October 2015, and all reconstructions were performed by one orthopedic surgeon with several years of experience in MPFL reconstructions. The patient charts were reviewed for data collection, and the questionnaires were sent digitally in Dutch, with a link to a secured system named Patient Reported Outcome Measures (PROMs). Primary outcome of this research was the persistence of instability, defined as at least one re-dislocation or subluxation. Secondary outcomes were postoperative complications, additional surgeries, and the postoperative subjective clinical outcomes. The subjective clinical outcomes were measured by using several questionaires: the Kujala score for knee specific pain and function (0-100), in which lower scores represent greater pain/disability; The Numeric Rating Scale (NRS) for pain (0-10, 0 = no pain and 10 = severe pain); the EuroQol 5D (EQ-5D) for health-related quality of life with five dimensions (combined in the Dutch time trade-off (TTO) score, in which 1 = full health and -0,329 = the worst possible score) ; the visual analogue scale (VAS) for self-rated health (0-100, 0 = worst imaginable health state and 100= best imaginable health state) and the IKDC subjective knee form for knee specific function (0-100, a higher score represents better function, and a lower score means less function). All patients underwent preoperative radiologic imaging. The patellar height was measured on a preoperative lateral radiograph, using the Caton-Deschamps index; an index of >1.2 was considered abnormal[5]. The conventional radiograph and a computed tomography (CT) scan were used to determine the degree of trochlea dysplasia, and were classified according to the Dejour classification[8]. The TT-TG distance was measured on the CT scan, and a distance of >15 mm was considered abnormal.[13]

Patients

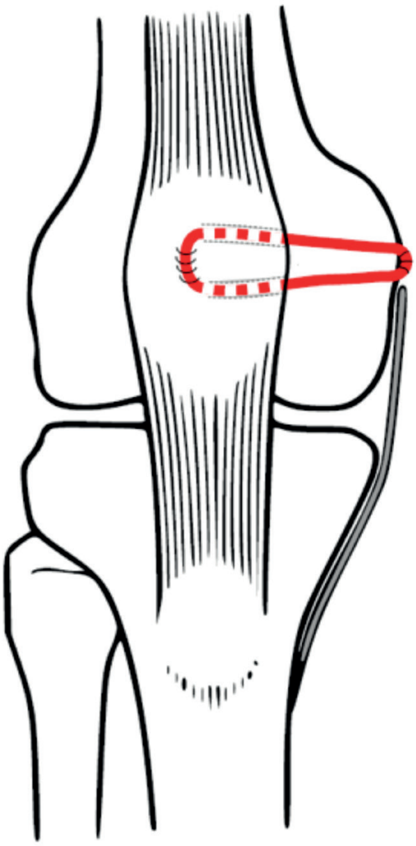
During the study period 33 isolated dynamic MPFL reconstructions were performed. On preoperative radiographs, skeletally immaturity was determined by assessing the physis, 16 cases were excluded because of skeletally maturity. One patient was excluded due to a previous surgery in the ipsilateral knee and one mental disable patient was excluded because of inability to respond to the questionnaires.

Twelve patients (fifteen knees) were included. Recurrent patellar instability, with a minimum of two dislocations, impairment in activities of daily life and the inability to participate in sports, and failure of non-operative treatment, were an indication for the MPFL reconstruction.

The patient characteristics are described in table 1, the average age at time of surgery was 13.6 years (SD 2.2, range 9-18).

Surgical technique (Figure 1)

Figure 1: Technique of the dynamic MPFL reconstruction.



The gracilis tendon was harvested, the graft was looped around the adductor tendon, led through the second and third layer of the retinaculum and fixed to the patella with two transverse patellar bone tunnels.

For reconstruction, a hamstring autograft was used, by preference the gracilis tendon. It was harvested by making an incision over the pes anserinus.
One incision was made at the medial border of the patella for the patellar attachment, and one at the medial femoral epicondyle for the femoral attachment. Chassaing and Tremoulet[6] and Arendt[2] describe the femoral fixation, in which the graft is looped around the adductor tendon, and the two free ends are led through the second and the third layer of the retinaculum. Schottle et al22 and Arendt2 describe the patellar fixation, in which the graft is fixed with two transverse patellar bone tunnels. The tunnels were drilled from the medial border to the anterior patellar cortex, and the free ends were passed through the tunnel. Subsequently the graft was attached to the patella, and the isometry of the graft was controlled through full range of motion before fixation with sutures. No hardware is used.

Statistical analysis
Descriptive analyses were performed due to the low number of patients.

RESULTS

All the results are summarized in table 1. The mean follow-up period was 51.8 months (SD 26.2, range 18-93).

Radiological evaluation
The Caton-Deschamps index was abnormal in 66.7% of the patients; severe trochlear dysplasia (Dejour type D) was found in 46.7% of the knees. The TT-TG was in all patients, in which it was determined, abnormal. Due to the quality of radiographs, or missing CT scans, it was impossible to determine the TT-TG distance in four patients.

Objective clinical outcomes
Recurrent dislocation occurred in three knees (20%) and subluxation was reported in one knee (6.7%). The three knees with a dislocation had additional surgery to restore the patellar stability. These patients had severe osseous abnormalities with trochlear dysplasia type D (2 patients) and type B (1 patient) and abnormal TT-TG distance, two had an increased Caton-Deschamps index.

Table 1: Patient characteristics, radiologic evaluation and clinical outcome.

Patient number	Gender	Side	Age at surgery (years)	Follow -up in (months)	Age at follow-up (years)	TT-TG distance (mm)	Patellar height (Caton DeChamps index)	Trochlear dysplasia (Dejour type)	Recurrent instability
1	Male	Left	14	26	17	25	1.4	A	No
2	Male	Right	15	60	20	19	1.2	B	Dislocation
3	Male	Left	9	43	13	21	1.5	D	Dislocation
4	Female	Left	12	93	20	20	1.2	C	No
5	Female	Left	14	91	21	23	1	B	No
6	Female	Right	11	36	14		1.5	D	No
7	Male	Left	14	29	16	23	1.5	A	No
8	Female	Right	13	28	15	19	1.2	A	Subluxation
9	Male	Left	16	80	23	20	1.5	D	No
10	Male	Left	15	41	19	21	1.2	A	No
11	Female	Right	15	66	20	20	1.3	D	No
12	Female	Left	12	22	14		1.3	D	No
13	Male	Right	18	60	23		1.3	D	No
14	Male	Right	14	18	16		1.4	A	No
15	Female	Right	12	84	19	27	1.4	D	Dislocation

Patient number	Other complication	Additional surgery	Kujala	NRS pain	TTO score	health status	IKDC
1	Patella fracture	Yes	44	2	0.775	59	45.98
2	No	Yes	79	0	1	90	79.31
3	No	Yes	73	3	0.775	99	58.62
4	No	No	91	7	1	91	73.56
5	No	No	95	0	1	100	90.80
6	Over tightening	Yes	67	6	0.775	55	47.13
7	No	No	85	0	0.719	95	83.91
8	No	No	86	1.5	0.773	90	72.41
9	No	No					
10	No	No	75	2	0.811	82	77.01
11	No	No	91	3.5	1	90	71.26
12	No	No	75	1	0.897	90	62.07
13	No	No					
14	No	No	100	0	1	98	81.61
15	No	Yes					

In all patients without recurrent dislocation were radiologic abnormalities found; five patients had trochlear dysplasia type D and an abnormal Caton-Deschamps index. Two of these five patients had also an abnormal TT-TG distance, in the other three patients the TT-TG distance could not be determined.
Two complications that required additional surgical intervention occurred; one patient had a patella fracture and one patient had over tightening of the graft due to growth after three years. This particular patient underwent a Z-plasty to lengthen the graft.
In total, five patients underwent additional surgery, resulting in a reoperation rate of 33.3%.

Subjective clinical outcomes
Three patients did not respond to the questionnaires. Table 1 shows large differences in the results of every questionnaire. The mean Kujala score is 80.1 points (SD 15.1) and the mean of the NRS pain is respectively 2.2 (SD 2.3). At the EQ-5D TTO score, a mean of 0.9 (SD 0.1) is found, and at the EQ-5D health status a mean of 86.6 (SD 14.7) is scored. The mean of the IKDC is 70.3 (SD 14.2).
It is interesting, that none of the patients scored the worst score on one of the five dimensions of the EQ-5D. This results in high TTO scores, which means that none of the patients had severe problems with mobility, self-care, usual activities, pain/discomfort or anxiety/depression. The patients with complications (patella fracture and over tightening) had the lowest scores at the Kujala score, the EQ-5D health status and the IKDC. The patella fractured due to the patellar bone tunnels. In case the patella fracture would be excluded the mean of the would be Kujala would be 83.4 points, and the mean of the NRS pain 2.2; EQ-5D TTO 0.9; EQ-5D health status 89.1 and the IKDC would be 72.5.

DISCUSSION

The main finding of this study is the acceptable recurrent instability rate of 26,7%; 20% of the knees had at least one recurrent dislocation, and 6.7% of the knees had a subluxation after the MPFL reconstruction. The recurrence rate falls within the ambit found in previous studies. In literature, a recurrent instability rate is highly variable (between 0-45%) and seems to depend on the used technique, the follow up time and the number of included patients.[1,7,14,16,17,25]

We compared the results to previously published papers with 7 or more patients. Abouelsoud et al1 and Nelitz et al17 both performed a static MPFL reconstruction with anchor fixation in immature patients, and reported no recurrent instability. Their patient groups consisted of respectively 16 and 21 patients, and had a mean follow-up of 29.3 months and 2.8 years. Abouelsoud et al1 investigated a technique by which the quadriceps tendon was harvested. It was left attached to the patella, and the free proximal part was fixed to the bone and periosteum of the medial epicondyle, as well as to the adductor magnus tendon. Nelitz et al17 used a technique in which the gracilis tendon was used as graft, and the femoral interference screw fixation was used. Both authors did not report on complications and on long-term growth disturbances. The major drawback of these static techniques is the risk of over tightening and injury of the physis, resulting in growth disturbance.23 Therefore, it is potentially a less safe and a less preferable technique compared to a dynamic technique without bony fixation to the femur. Lind et al[16] investigated a dynamic MPFL reconstruction technique in which the gracilis tendon was used as graft. The graft was looped around the adductor magnus tendon insertion, and sutured to the adductor tendon insertion area and proximal MCL insertion. They included 20 patients with 24 knees, with an average age of 12.5 years and a mean follow up of 39 months. They reported a considerably higher recurrence dislocation rate of 20%, and a subluxation rate of 25%.
An explanation for the recurrence rate in studies with skeletally immature patients is that the MPFL reconstruction is performed in the attendance of osseous abnormalities. These abnormalities are compromising the stabilisation of the patella when only a MPFL reconstruction is performed. Therefore, they can impair stability and subjective outcome.

In this study, the complication rate is acceptable, does not seem to cause growth disturbance, but the patellar bone tunnels can result in patella fracture and should be avoided.21 The technique is now modified, and currently the patellar fixation is to the periosteum of the patella by sutures. This fixation, without the use of bone tunnels in the patella, prevents the patella from fracturing. Consequently, the technique is safer and thus a preferable option in skeletally immature patients. Previous studies did not describe long-term complications. Abouelsoud et al1 and Lind et al16 did not report any complication, and Nelitz et al17 described only one patient with reduced flexion 6 weeks after surgery, however full range of motion was achieved with physical therapy.

Regarding the subjective outcomes, the present study shows a mean Kujala score of 80 and a mean NRS pain score of 2.2. Comparing the results with previous studies, the Kujala score is higher than the score Lind et al16 reported. They found a mean Kujala score of 71 at the final follow-up. However, they found an significant improvement when comparing it with the preoperative Kujala score (61). The studies with the static techniques, Nelitz et al17 and Abouelsoud et al1, both revealed higher Kujala scores, and also with a significant improvement (Nelitz et al17 from 72.9 to 92.8, Abouelsoud et al1 from 56 to 94). An explanation for the differences in Kujala score could be the complication of the patella fracture, this patient scored considerably lower than the other patients. Another explanation could be the rate of recurrent instability; the static techniques with no recurrence are showing higher scores.

Limitation of this study is the relatively small study group, due to the fact that surgery is not often performed in skeletally immature patients. Because of the small study group there was not enough data to perform an advanced statistical analysis. Another limitation is the absence of preoperative subjective outcomes, and for that reason the comparison in subjective clinical outcomes is missing.
One of the strengths of this study is the long follow-up; meanwhile eight out of fifteen patients have reached maturity. Six of these patients had no recurrence or complications and did not undergo additional surgery.

CONCLUSIONS

The presented technique for a dynamic MPFL reconstruction has an acceptable rate of recurrent instability. Although the technique is safe, the patellar bone tunnels cause the most severe complication. When this is avoided in the future by suturing the graft to the periosteum of the patella, the technique becomes even safer. The study showed decent subjective clinical outcomes, with scores within the range found in previous literature.

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CHAPTER 7

A Detaching, V-Shaped Tibial Tubercle Osteotomy Is A Safe Procedure With A Low Complication-Rate.

Akkie Rood
Jordy van Sambeeck
Sander Koëter
Albert van Kampen
Sebastiaan AW van de Groes

Submitted to: Archives of Orthopaedic Trauma and Surgery.

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ABSTRACT

Introduction: In patients with recurrent patellar dislocations, a tibial tubercle osteotomy (TTO) can be indicated to correct patella alta or an increased trochlear groove - tibial tubercle distance. Several surgical techniques are described. Previous studies emphasize that detaching osteotomies results in devascularisation, which can lead to non-union and tibial shaft fractures. The aim of this study was to report complication rates directly related to the surgical technique of a V-shaped TTO, where the tubercle is completely released from its periosteum using a step-cut osteotomy.

Methods: The retrospective case series comprised 263 knees in 203 patients who underwent a V-shaped TTO, with or without additional realignment procedures between March 2004 and October 2017. Data was obtained from available patient files. Complications were defined as minor or major.

Results: Thirteen major complications were registered (4.9%) including 2 tibial fractures (0,75%) and 1 non-union (0.37%). Five complications (1.9%) were defined as minor. Removal of the screws because of irritation or pain was seen in 22 cases (8.2%).

Conclusion: A V-shaped TTO is a safe procedure in comparison to other surgical techniques. The presumed higher risk for tibial fractures or pseudo-arthrosis could not be confirmed.

Key terms: MPFL, patellafemoral instability, tibial tubercle, TTO

INTRODUCTION

Patellofemoral instability is a common problem in adolescents. In case of recurrent patellar instability, surgical management results in a lower risk of recurrent dislocation than conservative management [1]. Tibial tubercle osteotomy (TTO) is indicated in patients with recurrent patellar dislocations due to patella alta or an increased tibial tubercle trochlear groove (TT-TG) distance. Several types of osteotomies are described: the modified Elmslie-Trillat medialisation technique [2], the Fulkerson anteromedialisation technique [3], a sliding tibial tubercle osteotomy [4] and techniques in which the tibial tuberosity is completely detached [5]. A systematic review by Payne et al. concluded that the risk of complications is related to the employed technique [6]. In his review the complication rate lies between 3.3 and 10.7%. When performing a V-shaped TTO, the tibial tubercle with periosteum is completely detached from the tibia and a step cut osteotomy is used [7]. Some authors suggest that maintaining the medial and/or distal periosteum at the tubercle when performing an osteotomy is crucial for preserving the vascularization and osteotomy union [8, 9]. Also, the fear of causing a tibial stress fracture when using a step-cut osteotomy lives among surgeons [10]. Payne et al. stated that osteotomies that involve complete detachment of the tubercle have an increased risk of non-union and tibial fractures compared with those in which a distal cortical hinge is maintained [6].

However, the hypothesized advantages of the V-shaped TTO are that the risk on non-union is low due to the triangular shape of the bone block with a twice as big bone contact area of trabecular bone and the intrinsically stable nature of the shape of the osteotomy in comparison to a sliding flat osteotomy. Only small sample size studies have been performed on this subject to our knowledge [5, 11]. Large studies reporting complication rates of a V-shaped tibial tubercle osteotomy are missing, but necessary to give a clearer view on this and can help determine the optimal technique. The aim of this study was to report complication rates directly related to the surgical technique of a V-shaped TTO, where the tubercle is completely released from its periosteum using a step-cut osteotomy.

MATERIAL AND METHODS

Data collection

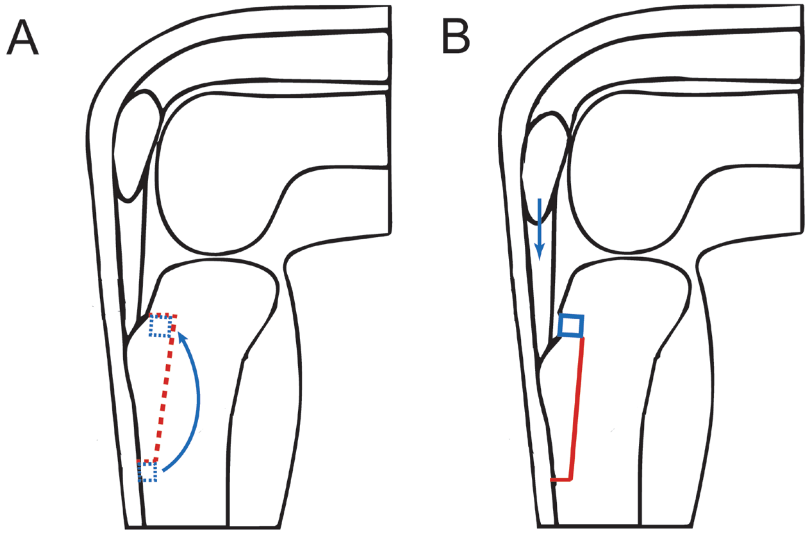
All patients operated between March 2004 and October 2017 in the Radboud University Medical Centre, Nijmegen, using a V-shaped tibial tubercle osteotomy (TTO) were included. The indication for a tibial tubercle transfer was recurrent patellar dislocations in combination with a patella alta (Caton-Deschamps index >1.2), as underlying anatomical risk factor after failure of conservative management with or without an increased TT-TG distance. Two experienced surgeons using a similar surgical technique performed all procedures. Additional simultaneous procedures were performed if indicated such as a medial patellofemoral ligament (MPFL) reconstruction, lateral release, vastus medialis obliquus (VMO) plasty or a trochlear osteotomy. Patient charts were reviewed for data collection. Follow-up was obtained at 6 weeks and 4 months postoperatively in case of fusion without further complications. Longer follow-up was only on indication.

Surgical technique

The tibial tubercle transfer was performed making a V-shaped osteotomy of the attachment of the patellar tendon on the tibial tubercle using a saw and osteotome (Fig. 1A), as earlier described by Caton and van de Groes [7, 12]. Through an anteromedial approach, the patellar tendon is identified and the periosteum is released. The tibial tubercle is completely detached on three sides with an oscillating saw and osteotome to be able to perform a distal transfer.

A piece of bone from the tibia is removed in order to correct the Caton–Deschamps index to 1 as planned preoperatively. This bone block was placed in the gap on the proximal side to enhance stability and to provide a more stable situation of the tuberosity (Fig. 1B). The osteotomy was fixed using two small fragment lag screws. The screws were countersunk and not placed in the same line to prevent breakage of the tubercle and irritation of the screw heads. Stable compression was obtained.

Figure 1: Schematic drawing of the V-shaped tibial tubercle osteotomy for transfer.



A: the red dashed line reflects the cut for complete detaching the tibial tubercle. The blue dashed line marks the small bone block that is transferred from distal to proximal. B: situation after distalisation of the tubercle with the bone part from distal put back proximally.

Aftercare

Post-operative care consisted of a removable long leg plaster cast with the knee in full extension for six weeks in the period until 2014. From 2014 to the present no cast is used. Only partial weight bearing was allowed in this period, and a maximal flexion of 70 degrees. If there were no complications after six weeks, full weight bearing and full range of motion was allowed.

Data analysis

Complications related to the surgical procedure were classified as minor or major, according to the criteria used in Payne's review article. [9] Major complications were defined as tibial fractures, non-union, neurovascular complications, infection and wound complications that required surgical intervention. Minor complications include events that are unlikely to have influenced the functional outcome or caused no permanent harm to the patient.

Statistical analysis

Descriptive statistics were used to analyse the frequency of complications as a percentage of total. A Chi –square test was performed to look at differences in male to female ratio, and an unpaired T-test to look at differences in age between the group with and the group without complications

RESULTS

Two hundred and sixty-three (263) knees in two hundred and three (203) patients were included. Descriptive statistics are displayed in table 1. The median age at operation was 19 years (range 12 - 49 years). Most patients were female (73.8%).

Table 1: Descriptive statistics.

Patient characteristics	
Number of patients	203
Number of knees	263
Mean age (range)	20.5 (12-49)
	N patients (%)
Female	194 (74)
Additional procedures performed	
None	123 (46)
VMO plasty	51 (19)
Trochlear osteotomy	50 (19)
Lateral release	16 (6)
MPFL reconstruction	7 (3)
Combined	80 (30)

Median follow-up was 4 months (range 3 - 120 months) because standard follow-up was only up to 4 months if uncomplicated. Most frequent reasons for longer follow-up were: recurrent dislocations, postoperative complications, consultation for contralateral knee issues and request for TTO hardware removal.

An overview of which specific additional procedures performed can be found in table 1. Out of the 263 knees, 144 (54.8%) had at least one additional procedure to the TTO. There was no significant difference in age between patients with and without complications (p= 0.80), but the amount of women in the group with complications was higher compared to the group without complications. (Chi-square 4.5765, p = 0.03).

Major complications

Table 2: Occurrence and demographics of complications TTO
Results N (%)

Results	N (%)
Major complication	**13 (4.9)**
Fracture	3
Tibial shaft	2
Tibial tubercle	1
Non- or malunion	6
Delayed union	4
Non-union	1
Malunion	1
Malposition bone block	2
Septic arthritis	1
Minor complication	**5 (1.9)**
Thromboembolic event	2
Wound infection	1
Delayed union	1
Delayed FROM	1

Thirteen knees (4.9%) had a major complication. An overview of complications is displayed in table 2. Two patients (0.76%) sustained a tibial shaft fracture at the side of the step cut performed during the transfer surgery. The first patient while jumping on one leg during rehabilitation 2.5 months after surgery, the other after 6.5 months after a fall. Both fractures were stabilized with a locking compression plate. There were two cases in which there was a problem with the part of bone removed from the distal side that was pressed

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into the proximal part of the osteotomy. In one patient the bone block became a loose body that was removed arthroscopically. In the second case this bone block was malpositioned directly underneath the patellar tendon and caused tendinopathy, and was surgically removed. There was one case of septic arthritis (0.38%) and one with a non-union (0.38%). The patient with a non-union was re-operated after 9 months. A fibrous layer on the V-shaped fragment was excised and a third screw was placed to increase stability, this resulted in consolidation after 5 months. Proximalisation of the tubercle without screw breakage was seen in three patients (1.14%), this was recognized after 10 days, 3 weeks and 3 months; all three patients had the screws revised after which the osteotomy fully consolidated. In one patient the malunion was seen after 4 years after a recurrent patellar dislocation. The bone was healed, but during the growth the screws were pulled oblique so the tubercle proximalised again. A correction TTO was performed. Screw breakage occurred only once, discovered 6 months after surgery but with consolidation of the osteotomy and a Caton index of 1.1 so no further action was needed. In one case the tibial tubercle fractured three days after surgery because of an epileptic insult with maximum quadriceps contraction so it was fixated with a small buttress plate.

Minor complications

In five knees (1.9%) minor complications occurred (table 2). Two patients (0.76%) had a thromboembolic event. The other three complications occurred only once (0.38%): a superficial wound infection with a S. Aureus for which this patient got antibiotics for 6 weeks, a deep flexion contracture of 90 degrees which restored without further surgery after 5 months to 130 degrees and a delayed union. This last patient had to wear an extension brace with restricted flexion without resistance up to 60 degrees until 5 months postoperatively, after which the osteotomy consolidated. No cases of persisting disability in range of motion were seen.

Hardware removal

Twenty-two knees had the screws removed because of pain or irritation (8.4%).

DISCUSSION

The major findings of this study are the low incidence of non-union and tibial fractures. Kanamiya et al suggest that when a complete detachment of the tibial tubercle is performed and the medial, lateral and distal periosteum is transected, this leads to a complete arrest of the blood flow and a higher chance of non-union [8]. From our data we cannot confirm this theoretical concept in practice. Compared to the non-union rate of 0.8% in 787 TTO's published by Payne et al. [6] in their systematic review, the incidence in our group (0.38%) is even lower. This could be due to the bigger contact area of the V-shaped osteotomy with more trabecular bone for better bone healing. Secondly, tibial fractures were only seen in 0.76%, again less than reported by Payne et al. [6] (2.4% when using a detached TTO) or Luhmann et al. [10]. There were no early tibial fractures. After the second tibial fracture, the aftercare was changed where instead of 50% only 10% of weight bearing was allowed for six weeks. Although both tibial fracture were seen after this first six weeks, we think that protecting the tibia in the first stadium of bone healing will give less excessive stress on the damaged cortex at the distal cut, which is perpendicular to the shaft, and so prevents tibial shaft fractures. In both cases, the piece of bone that was resected was not placed back proximally because it did not fit. This might have caused a lack of stability, which could be the reason the tibial shaft broke. Secondly, it is very important to make the distal cut carefully and not too far into the cortex of the tibia. If this happens, this will be the weak spot for stress rising.
In three cases the tibial tubercle proximalized without breakage of the screws. It has been recommended that these screws should be at least 2 mm longer than the measured bi-cortical distance to ensure adequate bite [13]. In retrospect this was not the case in two out of three situations.
In only one case the piece of bone that was trans positioned from distal to proximal became loose. So no additional fixation is necessary for this bone block besides compression between the cortices.

The infection rate (0.76%) was with once a septic arthritis and one superficial wound infection comparable to the findings of Payne et al. [6].
The other remarkable finding was the low number of screw removal in this case series. Most studies maintain percentages up to 50% of hardware removal in TTO. Payne found that in the complete tubercle detachment group this risk was 48.3%. One of the reasons why in this study this percentage is only as low as 8.4% is that we use the countersink when placing the screws. Secondly, all

patients got instructed that the hardware is only removed in case of specific complaints of the screws.
The most important weakness is the retrospective nature of this study, using only available patient charts. Because the highly specialized character of our clinical practice in patellofemoral instability, the chances that complications occurred without our knowledge are small. All patients were followed up until at least 4 months, so wound problems or non-unions would have been detected. It is very unlikely that tibial fractures were treated in another clinic. A distinct advantage of this study is its large sample size and the uniform technique that was used.

CONCLUSION

A V-shaped tibial tubercle osteotomy is a (relatively) safe procedure with a low complication rate. The risks on non-union and tibial fractures are particularly low, despite complete detachment of the periosteum and using a step cut osteotomy.

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7

CHAPTER 8

Complications of a self-centering sliding tibial tubercle osteotomy for patellofemoral instability

Jordy D.P. van Sambeeck
Akkie Rood
Siebren Tigchelaar
Sebastiaan A.W. van de Groes
Sander Koëter

Submitted to: Knee Surg Sports Traumatol Arthrosc.

ABSTRACT

Purpose: A tibial tubercle osteotomy (TTO) is a commonly performed procedure in young and active patients with patellofemoral complaints. Previous small patient series demonstrated a relatively high risk of complications, which appear to be technique dependent. The goal of this study is to quantify the risk of specific postoperative complications after a self-centering TTO technique in a large cohort.

Methods: Five hundred and twenty-nine knees in four hundred and forty-seven patients who underwent a self-centering TTO with at least one year of follow up were included. We performed a retrospective cohort review. Tibial fracture, osteotomy non-union, neurovascular complications, infection and wound complications that required surgical intervention were defined as major complications.

Results: The major finding in this study is the low incidence of non-union (0.6%) and tibial fracture (0.4%). In total 9 (1.7%) major complications were reported.

Conclusion: A self-centering TTO is a relatively safe technique with a low number of major complications.

INTRODUCTION

A tibial tubercle osteotomy (TTO) is used to correct patella alta or an increased tibial tubercle trochlear groove distance (TT-TG) in young patients with severe patellofemoral complaints. With a distalization or medialization of the tibial tubercle the anatomical abnormalities can be addressed. This increases patellofemoral stability and decreases abnormal patellofemoral contact pressures.[11] Different techniques for TTO have been described. Frequently used current methods are the modified Elmslie-Trillat medialization technique[3], the Fulkerson anteromedialization technique[5] and techniques in which the tibial tuberosity is completely detached. The recent review by Payne et al.[15] concluded that the risk of complications is related to the employed technique. In his review some techniques had a complication rate as high as 10.7%, whereas others had lower complications rate of 3.3%. Previously, the short- and long-term results of a self-centering technique were published.[9,19] Authors demonstrated good clinical results, low pain scores and a low amount of recurrent instability and only marginal increase of radiological signs for patellofemoral osteoarthritis at ten years after this procedure.[19]
Altogether, the previous literature indicates that there is a serious risk of either early or late complications after TTO. However, most previous studies are based on small case series, which might lead to false conclusions, because observations can be due to chance. The largest cohort is described by Cox et al. and included 116 procedures in 104 patients[3], other series ranged from 18 to 62 patients.[15] The goal of this large case series is to quantify the risk of specific postoperative complications related to a uniform self-centering TTO technique performed by two different surgeons in one center.

METHODS

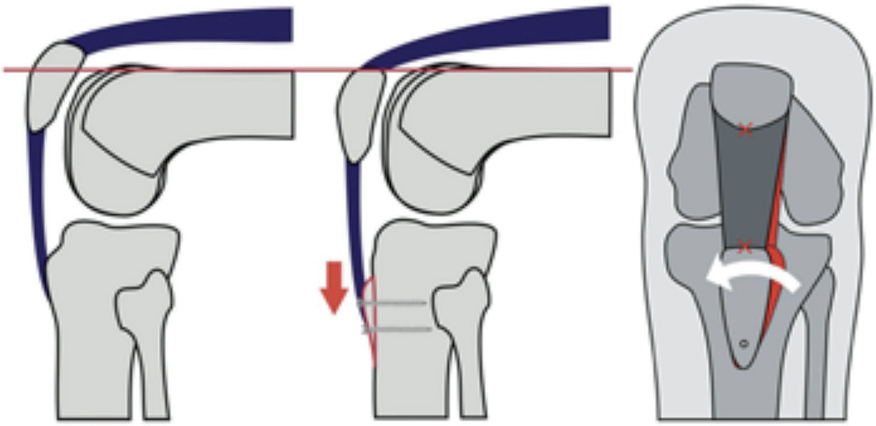
All patients who underwent either an isolated self-centering sliding TTO or a TTO procedure combined with a medial patellofemoral ligament reconstruction (MPFL) and/or a trochlear osteotomy between May 2008 and November 2016 with at least one year of follow up were included. All patients had closed epiphyseal growth plates. Data on complications was collected prospectively, all patient charts were retrospectively reviewed to check for completeness. Patients who were treated for patellar instability after a prior total knee arthroplasty (TKA) were excluded from analysis. All procedures were performed by two experienced orthopedic surgeons.

Complications related to the surgical procedure were classified as minor or major, according to the criteria used in Payne's review article.[15] Major complications were defined as tibial fracture, osteotomy non-union, neurovascular complications and infection and wound complications that required surgical intervention.

Surgical technique and postoperative care

The surgical technique that was performed is previously described (figure 1).[9,19] Additional simultaneous procedures such as an MPFL reconstruction and/or trochleoplasty were performed when indicated. Post-operative care consisted of a removable brace with the knee in full extension for six weeks. Full weight bearing was allowed as tolerated whilst wearing the brace and full range of motion was advised without bearing weight. A low-molecular-weight heparin was prescribed during the first six weeks. Follow-up of these patients was routinely six weeks post operatively and 6 months after surgery. On indication, the follow-up was longer.

Figure 1: Surgical technique



A lateral osteotomy in the frontal plane is performed, about 5 cm long and 0.75 cm thick. Medial soft tissues remain intact to the tuberosity. Patellar height can then be adapted and the tibial tuberosity is fixed temporarily, then the knee is flexed to 90 degrees. This centers the patella between the distal femoral condyles, causing the patella tendon to center the tibial tuberosity. In this position the tuberosity is fixed with two or three lag screws.

Statistical analysis:
A Chi-square test was used to detect differences in major and minor complications between sexes, whether or not patients had previous surgery, whether or not additional procedures were performed and between indications pain and instability. Fisher´s exact test was used if the observed value was 10 or lower or when expected count was equal to or lower than 5 with Chi-square analysis. If a complication occurred less than five times, no analysis was performed. Statistical analyses were performed using the statistical package SPSS 20.0 for WINDOWS (IBM SPSS, Chicago, IL, USA).

RESULTS

Five hundred and twenty-nine (529) knees in four hundred and forty-seven (447) patients were included in analysis. Two patients with patellar dislocation after a prior TKA were excluded. Descriptive statistics are displayed in table 1. Mean age was 23.2 years (range 13.8-59.9) and most patients were female (74%). Indications for TTO were recurrent patellar dislocations or instability, persistent patellofemoral pain with anatomic abnormalities or posttraumatic patella abnormality (patella alta after ruptured patellar tendon, patella baja after an anterior cruciate ligament reconstruction). Previous procedures were performed in 18% of patients. Additional procedures simultaneous to the TTO were performed in 57% of patients.

Table 1: Descriptive statistics

Patient characteristics	
Number of patients	437
Number of knees	529
Mean age (range)	23.2 (13.8-59.9)
	N patients (%)
Female (%)	389 (74)
Indication	
Patellofemoral pain	171 (32.3)
Patellofemoral dislocations	249 (47.1)
Miscellaneous	2 (0.4)
Previous procedures performed	
None	436 (82)
Arthroscopy	41 (7.8)
MPFL reconstruction	15 (2.8)
tibial tubercle transposition	7 (1.3)
with lateral release	9 (1.7)
VMO-plasty	3 (0.6)
trochleoplasty	1 (0.2)
Miscellaneous	9 (1.7)
Additional procedures performed	
None	227 (43)
MPFL reconstruction	248 (47)
Trochleoplasty and MPFL reconstruction	53 (10)
Lateral lengthening	16 (3.0)

Frequency and distribution of complications are displayed in table 2. Major complications related to the surgical procedure were reported in 9 patients (1.7%). These major complications included: one tibial fracture at the site of a large AO screw of a prior tibial tubercle osteotomy performed elsewhere requiring internal plate fixation and one patient with a fracture of the tibial tubercle after a fall from the stairs 3 months postoperatively requiring open reduction and internal fixation. A nonunion was observed in three patients (0.6%), of who two required subsequent surgery and one was treated with 6 additional weeks of cast immobilization. One patient suffered a deep wound infection, which required surgical debridement and one patient suffered a low-grade infection, which was arthroscopically debrided. In two patients a large

hematoma was surgically evacuated. Minor complications included superficial wound infection treated with antibiotics in five patients. Wound infection was more common in patients who had previous surgery performed ($P<0.05$). Two patients had a thromboembolic event (TEE).
Screws were removed after consolidation of the osteotomy in 47% of the cases. Indications for screw removal were compression pain at the screws or at patient demand. Screws were removed more often in female than in male patients ($P<0.05$) and in patients with patellofemoral pain prior to surgery ($P<0.05$).
Nine patients had a reduced ROM requiring manipulation under anesthesia.

Table 2: Number of complications

Results	N
Major complication	
Nonunion	3
Fracture	2
Deep infection	2
Wound complications	2
Minor complication	
Superficial infection	5
Tromboembolic event	2

DISCUSSION

In this study, we describe the largest cohort of patients with a tibial tubercle osteotomy (TTO) to date. The major findings of this study are the low incidence of non-union and tibial fracture after a self-centering technique of tibial tubercle transposition in a large cohort. The rate of nonunion in this cohort (0.6%, 3/529 procedures) is lower than the incidence Payne et al.15 reported in their systematic review (0.8%, 6/787 procedures). Two patients (0.4%) sustained a postoperative fracture, one of the tibia and one of the tibial tuberosity. In Payne's review article the rate of fracture was 1.0%.
The non-union rate is related to the technique. When only the lateral periosteum is transected in order to make the osteotomy and the medial and distal periosteum remains intact, the blood flow decreases 25%. If a complete detachment of the tibial tubercle is performed and the medial, lateral and distal periosteum is transected, this leads to a complete arrest of the blood

flow[8] and a higher chance of non-union.
Fractures seem to be caused by mechanical issues. With this technique tibial fracture is rare. In other series fractures did occur, both acute and delayed.[2,9,13,16,17,20] In a previous article[9] two fractures occurred (one acute and one late in a cohort of 29 patients) when a step cut osteotomy (such as employed in total knee arthroplasty) was used, this produced a stress riser in the tibia and weakens the cortex. This can also lead to late fractures, usually a few months after surgery caused by bone fatigue induced by altered tibial biomechanics. In this series only one tibia fracture occurred at the site of a removed large AO fragment screw hole from a previous osteotomy in a revision case. Large fragment screw might have a higher change of fracture after removal then small fragment screws because of cortical weakening. In retrospect perhaps a staged approach would have been wiser, with removal of the screws first and a TTO only after complete bone healing.
Post-operative infections were seen in seven patients (1.3%) with 2 deep infections and 5 superficial wound infections. This is comparable to the rate of infection in the systematic review of Payne et al.15 In most of the reviewed articles by Payne[15] only patients with primary surgery were included, while in our cohort infection was more often seen in patients who had previous surgery.
Two patients had a TEE, despite the use of low-molecular-weight heparin (LMWH) for six weeks. Both the NICE committee and the American College of Chest Physicians (ACCP) guideline recommend against thromboprophylaxis in patients with lower limb immobilization[1,4], but evidence is weak.
None of the patients who had an isolated TTO had decreased ROM, but a decreased ROM was observed in nine patients with additional procedures, such as a MPFL and/or trochlea osteotomy implicating that the cause of the decreased ROM is intra articular fibrosis (arthrofibrosis) induced by intra- or periarticular surgery. These findings are in line with results published in previous literature, describing a higher change of decreased ROM after all types of trochlea osteotomy and after MPFL reconstruction.[10,18,21] In MPFL reconstruction this complication seems to be related to non-anatomical femoral tunnel placement.[14] Patients with preoperative patellofemoral pain and female patients had a higher chance of postoperative hardware removal.
Some other techniques, like the Hauser technique[7], were abandoned because they resulted in a unacceptable high chance of patellofemoral osteoarthritis due to a rise in patellofemoral pressure due to overcorrection. Newer, more subtle stabilizing techniques, can also result in a higher change of osteoarthritis[12,13] induced by higher pressure in the patellofemoral and tibiofemoral compartment of the knee. Depending on imaging alone for the

degree of correction, has a high-risk of overcorrection of the tibial tubercle in medial direction. To prevent this long-term complication, other authors use different intra operative measurements. Recently Arendt described a new physical exam measurement, the tubercle-sulcus angle (TSA), which can be performed in the operating room[6]. With a self-centering sliding technique overcorrection in medial direction is highly unlikely and intraoperative measurement are unnecessary. In a previous article on this technique, there was only a modest increase in radiological patellofemoral osteoarthritis of 0.35 with a maximum of grade 2 on the Kellgren-Lawrence scale at ten years follow up.[19] The main weakness of this study is its design, a historical case series. However, data on complications and recurrent dislocations were collected prospectively, and all patient records were reviewed to avoid data loss and prevent underestimation of early complications. A distinct advantage of this study is its large sample size, uniform technique and protocolized postoperative care.

CONCLUSION

A self-centering sliding tibial tubercle osteotomy is a safe surgical technique with a low number of major complications.

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CHAPTER 9 | SUMMARY

In this thesis, the different treatment options for patellofemoral instability are evaluated: non-operative treatment after a first patellar dislocation and the different surgical options in case of insufficient stabilizing capacity of the medial stabilizing soft tissues or a patella alta.

Chapter 1 is a general introduction about the current state-of-the-art strategies in patellofemoral instability. The etiology and the possible causes of patellar instability are discussed. The key is to find the anatomical abnormality and then formulate the right treatment for the pathology. Several conservative and operative treatment options are described. Then the main question will be which treatment is preferred considering both short- and long-term follow-up.

Chapter 2 describes a randomized, prospective trial looking at the conservative treatment after a primary patellar dislocation. Eighteen adult patients sustaining a first patellar dislocation without any previous surgery on the affected knee were included. After immobilization with a long dorsal leg splint for a week, patients were randomized into two groups: immobilization with a tape bandage or a long cylindrical leg cast for another 5 weeks. Outcome measurements were the knee function, the Lysholm Knee Scoring Scale and recurrent dislocations. Tape resulted in a significantly better Lysholm score at 6 and 12 weeks after the dislocation ($p<0.05$), but remarkably this difference was maintained after 5 years follow up ($p<0.01$). Clinically functionality of the knee was better after 1-year follow-up in the tape group. In both groups, no recurrent dislocations occurred. We concluded that stabilizing the patella with tape after a primary patellar dislocation results in superior clinical outcome as compared to immobilization with a cylindrical walking cast and that these superior outcomes are maintained for as long as 5 years after treatment.

In **Chapter 3** we describe the surgical technique of the dynamic Medial PatelloFemoral Ligament (MPFL) reconstruction using a hamstring autograft. The procedure is explained and illustrated step by step. The Hamstring tendon, preferable the tendon of the gracilis or the semitendinosus of the ipsilateral knee, is used for reconstructing the ligament. On the femoral side, the tendon is attached dynamically. The graft is blindly tunneled around the adductor tendon or only trough de medial retinaculum, leaving the synovial tissue intact. On the patellar side, the tendon is tunneled periosteally and fixated to the periosteum with sutures. No hardware or bio screws are used. We believe that this technique is a good alternative to the static variant to create a stable patellofemoral joint, easier to perform and with a much lower risk of overtightening the graft.

The biomechanical differences between the static and dynamic MPFL reconstructions are described in **chapter 4**. Seven fresh frozen cadaveric specimens were utilized in an in-vitro knee loading apparatus. Tekscan pressure sensitive films were fixated to the retropatellar cartilage to measure patellofemoral pressure (mean and peak pressure), contact area and the location of the center of force during flexion cycles from 0 to 110 degrees of flexion.
Four different conditions were tested: a native situation with an intact MPFL, a dynamic MPFL reconstruction, a partial dynamic MPFL reconstruction and a static MPFL reconstruction. The hypothesis was that a dynamic MPFL reconstruction would result in the most resembling outcome measurements as compared to the native situation. The results showed that the static MPFL reconstruction created peak and mean pressures that were 3 to 5 times higher in flexion angles from 60-110 degrees ($p<0.001$). There were no differences between the two dynamic reconstruction techniques and the intact situation ($p>0.05$). The center of force in the static reconstruction showed a more medial replacement on the patella from 50-110 degrees of flexion compared to the other conditions. The contact area was comparable in all situations. We concluded that the dynamic MPFL reconstruction produced patellofemoral pressures that are similar to the intact the situation and could therefore be a safer procedure than the static variant, as it is suggested that abnormal peak stresses may lead to anterior knee pain and early secondary osteoarthritis.

Possible complications that can occur in relation to a dynamic MPFL reconstruction are described in **chapter 5**. In this chapter we analyze a relatively large retrospective cohort of 193 knees in 179 patients who underwent a dynamic MPFL reconstruction between 2009-2015. The surgical technique of the dynamic MPFL reconstruction was as described earlier (see chapter 3), except for the fixation on the patella where we utilized bony tunnels in this clinical cohort. Thirty-nine complications (20.3%) were registered, with twelve major (5.6%) and twenty-seven minor complications (14.7%). Seven patients sustained a patellar fracture, not related to a fall or high impact trauma. There were sixteen cases of subjective persistent instability (8.1%) of which ten had a positive apprehension test (5.1%). In conclusion, this is the largest cohort in literature that describes the complications of a (dynamic) MPFL reconstruction. Bone tunnels on the patellar side are discouraged because of a higher risk on patellar fractures, especially in men.

The younger the patient sustaining a first patellar dislocation, the higher the risk of persistent patellofemoral instability. Although generally after primary patellar dislocation conservative treatment is the treatment of choice, in children or adolescents a direct operative stabilization is defendable. However, when performing surgery on the growing bone, the physis can be damaged with possible growth disturbances. For this specific group of patients, in theory, the dynamic MPFL reconstruction could be the preferred technique. Because stabilization is accomplished without bony fixation point, the epiphyseal plates remain undamaged. The results of a small cohort of twelve skeletally immature patients who underwent an isolated dynamic MPFL reconstruction in fifteen knees were analyzed in **chapter 6.** Hence, all patients had open physeal plates at time of surgery. The technique of the partial dynamic MPFL reconstruction was identical to the one described in **chapter 4**, with a dynamic fixation on the femoral side and attachment to the patella with bone tunnels. Mean follow-up time was 4 years. Preoperative patellar height, TT-TG distance and the degree of trochlear dysplasia were documented. The primary outcome measure was recurrent patellofemoral instability. Secondary outcome scores were complications, need for additional surgery and subjective clinical outcome measurements analyzed with the Kujala score, IKCD, NRS pain, and EQ-5D questionnaires. Mean patellar height measured by the Caton-Deschamps ratio was 1.3, mean TT-TG distance was 21.6 mm and almost half of the group had a severe trochlear dysplasia. Postoperative instability occurred in 26.7%. Complications were registered in 13.3%. One third (33.3%) required a second surgery to stabilize the patella. This study showed that this dynamic technique for reconstructing the MPFL is a safe option in the skeletally immature patients. Most complications are, again, related to patellar bone tunnels and should be avoided. The incidences of recurrence of patellofemoral instability as the functional outcome measurements of this dynamic technique are acceptable and comparable to other studies.
In **chapter 7** and **chapter 8** the complications of two different types of tibial tubercle osteotomies (TTO's) are described and analyzed.
Chapter 7 describes the complications after a V-shaped tibial tubercle osteotomy where the tibial tubercle is completely detached from the periosteum. Two hundred and sixty-seven knees in two hundred and six patients operated between 2004 and 2017 were included. We analyzed the registered complications, divided into minor and major complications. Eighteen complications (6.8%) were recorded, from which thirteen major (4.9%). In two cases a tibial fracture occurred (0.75%), non-union was only seen

once (0.37%). Removal of hardware because of pain or irritation was registered in twenty-two cases (8.2%). We concluded that the V-shaped TTO is a safe technique with similar incidence of tibial fractures or non-union compared to other techniques.

Chapter 8 is an overview of a large cohort of five hundred and twenty-nine knees in four hundred and seventy-four patients. All underwent a self-centering TTO, with or without accompanying procedures, with at least one year of follow up. Patients' data was collected between 2008 and 2016. Complications were again divided into major and minor complications. In total, sixteen complications were registered (3.0%), 9 were major (1.7%). Especially the low incidence of two non-union cases (0.6%) and tibial fractures (0.4%) is remarkable. We can conclude that the sliding, self-centering osteotomy of the tibial tubercle is a safe technique.

CHAPTER 10 | DUTCH SUMMARY / NEDERLANDSE SAMENVATTING

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Dit proefschrift geeft een overzicht van de verschillende behandelopties bij patellofemorale instabiliteit. Er is gekeken naar de conservatieve behandeling na een eerste patella luxatie, de verschillende operatieve behandelingen bij een insufficiëntie van de mediale stabiliserende structuren en bij een patella alta.

Hoofdstuk 1 geeft een algemene introductie over de huidige inzichten bij patellofemorale instabiliteit. De etiologie en verschillende oorzaken worden besproken. Het belangrijkste is om de anatomisch afwijking op te sporen en dan de behandeling hierop aan te passen. Er zijn veel verschillende conservatieve en operatieve behandeling beschreven. De vraag is welke behandeling op de korte en op de lange termijn superieur is.

Hoofdstuk 2 beschrijft een gerandomiseerde, prospectieve studie waar gekeken wordt naar de conservatieve behandeling na een primaire patellaluxatie. Achttien volwassen patiënten met een primaire patellaluxatie zonder eerdere operaties aan de aangedane knie zijn geïncludeerd. Na een week een bovenbeens achterspalk te hebben gehad, zijn de patiënten gerandomiseerd in twee groepen: tape en gipskoker immobilisatie voor nog vijf weken. Uitkomstmaten zijn de functie van de knie, de Lysholm Knee Scoring Scale en recidief luxaties. Tape resulteerde in een significant beter Lysholm score op zes en twaalf weken na luxatie ($p<0,05$), maar ook na vijf jaar follow-up ($p<0,01$). Ook de kniefunctie in de tape groep was beter na 1 jaar follow-up. Er waren geen recidief luxaties. De conclusie is dat immobilisatie met tape na een primaire patellaluxatie resulteert in superieure klinische uitkomsten vergeleken met gips en dat deze uitkomsten gunstiger blijven tot zelfs 5 jaar na behandeling.

In hoofdstuk 3 wordt de techniek van de dynamische mediale patellofemoral ligament (MPFL) reconstructie beschreven. Hierbij wordt de procedure stapsgewijs uitgelegd en geïllustreerd. Een hamstringpees, meestal van de musculus gracilis of de musculus semitendinosus van de ipsilaterale knie, wordt gebruikt om het ligament te reconstrueren. Deze wordt dynamisch verankerd femoraal. Hierbij wordt de pees wordt om de adductorpees geleid of alleen door het mediale retinaculum waarbij het synovium intact wordt gelaten. Aan de patellaire zijde wordt de graft getunneld tussen de patella en het periost en periostaal vastgehecht. Er wordt geen gebruik gemaakt van lichaamsvreemd materiaal in de vorm van (bio)schroeven. Wij geloven dat deze techniek een goed en veilig alternatief is voor de statische MPFL-reconstructie om een stabiel patellofemoraal gewricht te creëren. Daarnaast heeft precieze plek waar de graft wordt gefixeerd bij de dynamische MPFL-reconstructie een grotere marge met minder risico dat de graft onder te veel spanning wordt gefixeerd.

De biomechanische verschillen tussen de statische en de dynamische MPFL-reconstructies worden verder bekeken in **hoofdstuk 4**. In een kadaverstudie worden zeven vers gevroren kadaver specimens getest in een in vitro knie loading apparaat. Tekscan drukmeters die gefixeerd zijn op het retropatellaire kraakbeen meten de patellofemorale druk (gemiddelde en piekdruk), contact oppervlakte en de locatie van de center of force tijdens gefixeerde flexiehoeken van 0 tot 110 graden. Vier verschillende condities werden getest: een intacte MPFL en een dynamische, partieel dynamische en statische MPFL-reconstructie. De hypothese was dat een dynamische MPFL-reconstructie de meest vergelijkbare resultaten zou geven vergeleken met de intacte situatie. Uit de resultaten blijkt dat de statische MPFL-reconstructie resulteert in een drie tot vijf keer hogere druk (zowel piek als gemiddelde druk) in flexiehoeken van 60 tot 110 graden ($P<0{,}001$). Er zijn geen verschillen tussen de (partieel) dynamische reconstructies en de intacte situatie ($P>0{,}05$). De centre of force in de statische reconstructie groep verplaatst meer naar mediaal op de patella van 50-110 graden flexie vergeleken met de andere condities. Het contactoppervlak is in alle condities vergelijkbaar. Concluderend resulteert de dynamische MPFL-reconstructie in vergelijkbare patellofemorale drukken vergeleken met de intacte situatie. Dynamiseren van de MPFL-reconstructie zou daarom een veiligere optie zijn dan de statische MPFL-reconstructie gezien de suggesties dat abnormale piek drukken kunnen lijden tot anterieure kniepijn vroege secundaire artrose.

De complicaties die kunnen optreden na een dynamische MPFL-reconstructie worden beschreven in **hoofdstuk 5**. In een grote retrospectieve case series zijn de gegevens van 193 knieën (179 patiënten) die tussen 2009-2015 een dynamische MPFL-reconstructie hebben ondergaan geanalyseerd. De chirurgische techniek van de reconstructie is conform hoofdstuk 3, behoudens de fixatie aan de patellaire zijde waarbij gebruik is gemaakt van twee boortunnels in de patella. 39 complicaties (20,3%) zijn geregistreerd, waarvan 12 (5,6%) major en 27 (14,7%) minor. Zeven patiënten hadden een patellafractuur zonder dat er een val of een trauma met hoge impact aan vooraf is gegaan. Er waren 16 gevallen (8,1%) van persisterende instabiliteit waarvan er tien een positieve apprehensiotest hadden (5,1%). Concluderend kan er worden gezegd dat dit het grootste cohort in de literatuur is dat de complicaties van een (dynamische) MPFL-reconstructie heeft geanalyseerd. Het gebruik van boortunnels voor fixatie aan de patella geeft een verhoogd risico op patellafracturen, vooral bij mannen, en wordt daardoor afgeraden.

De kans op persisterende patellofemorale instabiliteit na een eerste luxatie is vele malen groter op jonge leeftijd. Hoewel over het algemeen na een primaire patellaluxatie de aanbevolen behandeling conservatief is, is directe chirurgische stabilisatie bij kinderen en adolescenten zeker te verdedigen. Echter ligt er een beschadiging aan de epifysairschijf en de mogelijk hierop volgende groeistoornissen op de loer. Gezien de dynamische MPFL-reconstructie geen gebruik maakt van benige structuren, is dit theoretisch een ideale techniek voor de nog niet uitgegroeide patiënt. De resultaten van een klein cohort van twaalf onvolgroeide patiënten met open groeischijven welke een geïsoleerde dynamische MPFL-reconstructie hebben gehad beschreven in **hoofdstuk 6**. Hiervoor is partieel dynamische techniek gebruikt conform beschreven in **hoofdstuk 4**, met een dynamische fixatie femoraal en aan de patellaire zijde door middel van twee transversale boortunnels. De gemiddelde follow-up was 4 jaar. Preoperatieve patella hoogte, TT-TG afstand en de mate van trochlea dysplasie zijn vastgesteld. De primaire uitkomstmaat was recidiverende patellofemorale instabiliteit. Secundaire uitkomstmaten waren complicaties, de noodzaak tot additionele chirurgie en subjectieve klinische uitkomsten geanalyseerd met de Kujala score, IKDC, NRS pijn en EQ-5D vragenlijsten. De gemiddelde patella hoogte volgens Caton Deschamps was 1.3, de gemiddelde TT-TG afstand was 21.6 mm en 46.7% had ernstige trochlea dysplasie. Postoperatieve persisterende patella instabiliteit lag op 26.7%. Complicaties waren geregistreerd in 13.3%. Één derde van deze patiënten (33.3%) had een tweede aanvullende patella stabiliserende operatie nodig tijdens follow-up. Deze studie laat zien dat de gebruikte techniek voor een dynamische MPFL-reconstructie een veilige techniek is. Het grootste deel van de complicaties worden ook hier veroorzaakt door fracturen in de patella door de boortunnels, welke moeten worden vermeden. Zowel de incidentie van recidiverende patellofemorale instabiliteit als de klinische uitkomst scores bij deze dynamische techniek zijn acceptabel en vergelijkbaar met wat bekend is uit de literatuur.

In **hoofdstuk 7** en **hoofdstuk 8** worden de complicaties van 2 verschillende soort tuberositas osteotomieen (TTO's) beschreven.
Hoofdstuk 7 beschrijft de complicaties van een V-vormige tuberositas osteotomie waarbij de tuberositas volledig wordt losgemaakt van het periost

voordat deze wordt verplaatst. In een retrospectieve patiënten serie zijn 267 knieën in 206 patiënten, geopereerd tussen 2004 en 2017, geïncludeerd. Er is gekeken naar de geregistreerde complicaties welke zijn onderverdeeld in minor en major. Achttien complicaties (6,8%) zijn geregistreerd, waarvan 13 als major (4,9%). In 2 casussen kwam een tibiafractuur voor (0,75%), pseudoartrose slechts één maal (0,37%). Verwijderen van het osteosynthesemateriaal vanwege pijn of irritatie is 22 keer geregistreerd (8,2%). Wij concluderen dat de V-vormige tuberositas osteotomie een veilige techniek is met een vergelijkbare kans op tibiafracturen of pseudartrose in vergelijking met andere technieken.

Hoofdstuk 8 beschrijft een serie van 529 knieën in 474 patiënten. Alle patiënten ondergingen een sliding tuberositas osteotomie, met of zonder begeleidende procedures met ten minste 1 jaar follow-up. De data was prospectief verzameld tussen 2008 en 2016. Complicaties zijn opnieuw onderverdeeld in minor en major complicaties. In totaal zijn er zestien complicaties geregistreerd (3,0%), waarvan 9 major (1,7%). Met name de lage incidentie zowel non-union (0,6%) als tibiafracturen (0,4%) zijn hier opvallend. Concluderend kunnen we stellen dat de sliding, self-centering tuberositas osteotomie een veilige techniek is.

CHAPTER 11 | DISCUSSION

Determining what the best treatment is for patients suffering from patellofemoral instability is challenging. Assessment of the anatomical abnormality is of upmost importance in order to tailor the surgical options to the underlying pathological condition. There is a distinction in treatment of primary dislocations and recurrent instability. With this thesis, we aim to contribute to further optimize the treatment of patients suffering from patellofemoral instability by considering:

1) Conservative treatment,
2) Medial PatelloFemoral Ligament (MPFL) reconstruction and
3) Tibial tubercle osteotomy for patellar distal realignment.

CONSERVATIVE TREATMENT

Although in recent literature there is a tendency of early surgical treatment in patellar instability, the best available evidence still advises to treat first-time patellar dislocations by immobilization if significant anatomical disorders are absent. [4,5,10,11,12] It is important to consider the balance between immobilation (to achieve a stabilized patella preventing recurrent early dislocation to promote soft tissue healing) and early active rehabilitation (to strengthen the musculature around the knee). In our prospective randomized controlled trial in **chapter 2**, it is clear that there is no place for prolonged immobilization with a cast after the first week. Strict immobilization for weeks results in muscle atrophy, which is a risk factor of patellofemoral instability by itself, and does not contribute to reduce the incidence of recurrent dislocation. We therefore advise against casting of patients with a primary dislocation. In our view, the best conservative treatment after a primary patellar dislocation is stabilization with tape or a brace for several weeks and direct active mobilization. The question remains if tape is preferred to bracing remains. Tape is cheap, but can cause irritation of the skin and has to be applied by a professional or experienced person. A brace is easily applied by the patient and can be removed when taking a shower or lying in bed. Kaewkongnok et al.3 performed a retrospective multicenter trial in 2018, comparing different conservative treatment options in patellar dislocations. Over six hundred patients were included receiving either two weeks of bracing, two weeks of bracing followed by bandage, four weeks of bracing and six weeks of bracing with increasing range of motion, or no bracing or immobilization at all. They found no differences in recurrent instability rates, and concluded that only a higher age resulted in a lower incidence of patellar dislocations.

This raises the question whether treatment of patients with first-time patellar dislocations has to take place in the hospital. Since there is no need for applying a cast, this specific care could perfectly done by general practitioners. In almost every case when a patient is presented at the emergency department, the patella has reduced spontaneously. This transition of care may be similar to the care around glenohumeral dislocations; a comparable shift of primary care from hospital to general practitioner has taken place. In the past, patients with a dislocated shoulder were immobilized for at least 6 weeks. Nowadays, direct early mobilization is general practice. We believe that, if alarm symptoms are absent (non-reducible, crepitations or locking), it is not necessary to treat primary dislocations of the patella in the hospital by a specialist. It can be treated first-line by general physicians. It would reduce the cost of health care without a decrease in quality.

MPFL RECONSTRUCTION

If conservative treatment fails or the anatomic abnormalities are too extensive, surgical stabilization of the patella is the preferred treatment. As stated before, the treatment of choice depends on the anatomical disorder. Reconstructing the MPFL has gained worldwide popularity and is nowadays performed on a daily basis in many orthopedic centers, employing many different techniques. Each year new techniques are published. In general they can be divided in static and dynamic reconstructions. In case of performing a static MPFL reconstruction, the biomechanical functioning is highly sensitive to the location of the attachment point on the femur.1 The dynamic MFPL reconstruction is less commonly performed or described in literature. The specific procedure we used in our in vitro study in **chapter 4** is described in detail in **chapter 3**. We conclude that the theoretical advantage of minimalizing the risk of over tightening is proven in our cadaveric study, and is therefore a distinct advantage over other (static) MPFL techniques. A second advantage of the dynamic technique is that the position of the femoral attachment is not as critical as in static techniques. Thirdly, no hardware is needed so it is cheaper and, in case of infection, less difficult to treat.

An interesting aspect about this reconstruction technique is the aim is loop the graft around the adductor tendon at the femoral attachment site. The idea is that during walking, the tendon tightens the graft dynamically to provide better stability at crucial moments in the flexion cycle. However, in practice a large, curved clamp is used to tunnel the graft between the synovial tissue and the retinaculum at the point of the adductor tendon, where it is pushed through the soft tissue. The actual looping around the tendon at that point is not checked, to prevent further damage to the tissue. Because it is interesting to know if the presumed looping of the graft really occurs, we used four cadaveric knees to assess this aspect of the surgical procedure. This was a small, unpublished, dissecting study. After reconstructing the MPFL, we opened the attachment-point on the femoral side to assess which reconstruction we had actually obtained. We found that in almost all cases, the graft was not looped around the tendon at all. The graft was only pushed through a part of the medial retinaculum. Although this specific soft tissue fixation is quite firm, one could imagine that this technique creates a more flexible fixation on the femoral site, which could jeopardize stability. Interestingly, this was not confirmed in the cadaveric study as described in **chapter 4**. We believe that the presumed dynamic active stabilization of the patella, by the adductor tendon pulling it more medially when it contracts during walking, is not largely contributing to the overall stability. Therefore, actual looping of the graft around the adductor does not seem to be as essential as commonly assumed in this procedure.

One of the major advantages of the dynamic MPFL reconstruction compared to the static techniques, is that the location of the femoral attachment point is much more forgiving. Performing a static MPFL reconstruction, the femoral attachment has to be at the isometric or the anatomic point earlier described.[1] It is most important that this specific point is carefully determined, and has to be exactly right on the spot. Although there is no discussion about the importance of this exact location, it remains hard to exactly palpate this point intra-operatively. Even with determining the exact location under fluoroscopic guidance, necessary millimeter accuracy is virtually impossible. If the femoral position is not exact, problems in range of motion, pain and early progression of patellofemoral osteoarthritis have been reported. This means that the femoral attachment of the graft should not be too proximally and/or too anteriorly. The MPFL has to constrain the patella in the first thirty degrees of flexion. In deeper flexion, the patella is fully captured by osseous structures. Hence, beyond 30 degrees of flexion the MPFL has no further use and can be completely loose. Another parameter, which affects the success of static MPFL reconstructions, is the amount of graft tensioning. Philippot et al found that the optimal tensioning of the MPFL reconstruction graft is 10N in 30 degrees of flexion.[8] On the other hand, Stephen et al[13] concluded that anatomically placed grafts during MPFL reconstruction tensioned to 2 N resulted in the restoration of intact medial joint contact pressures. In their study malpositioning of the femoral tunnels resulted in significant increased joint contact pressure, as did tensioning to 10 N.13 Optimal graft tension therefore remains under debate. Considering the specific complications related to a dynamic MPFL reconstruction as described in **chapter 5**, it is important to compare this to other studies described in literature. The review of Stupay et al. from 2015 shows an overview of the complications, with or without minor secondary soft-tissue surgery (e.g., release of the lateral retinaculum or advancement of the vastus medialis) with a follow-up of at least one year.[14] They made a distinction between "functional failure" (which included a positive apprehension-sign, subluxation or complete dislocation) and "complications". Major complications included patellar fracture, decrease in range of motion >10%, unable to run and return to surgery because of graft problems. They concluded that the major complication rate in recent literature was 0.46%. Assessing our own data concerning these specific complications, this percentage is 3.6% due to 7/192 patellar fractures. These 192 patients include the whole group who also had additional procedures to the MPFL reconstruction. If we filter this group with the ones who only received an MPFL reconstruction, the major complications drop to 2 patellar fractures (2/35= 5.7%). The reason that these rates are still higher compared to Stupay et al., is because of the high number of patellar fractures. In this cohort we used bone tunnels for patellar fixation, which led to a substantial number of patellar fractures. Because this is not an acceptable complication, we now advise against using bone tunnels for patellar fixation. The better alternative is fixation of the graft to the patella using a subperiosteal tunnel with sutures. This will not weaken the patellar bone, thereby avoiding this complication. Minor complications in our study group are: stiffness requiring manipulation under anesthesia, persistent pain, removal of hardware, wound infection, extensor lag and non-infectious wound complications. The complications in our study are acceptable compared to the result reviewed by Stupay et al.[14] (7.8% for the whole group, 0% in the isolated MFPL group).

As earlier discussed, the younger the patient the higher the chance of recurrent patellofemoral instability. Because the expected remaining growth, surgical strategies are more challenging. On the other hand, restoring normal patellofemoral tracking could result in a better anatomical development of the patellofemoral joint.[15]
The retrospective study in **chapter 6** assessed the effects of dynamical MPFL reconstructions in pediatric patients with open physeal plates. The 12 skeletally immature patients who received 15 dynamic MPFL reconstructions were

evaluated with a mean follow-up of 4 years. Again, a risk factor is using bone tunnels in the patella. This gives a higher risk on patellar fractures and should be avoided. Overall, one third of these patients required a reoperation. Normally this high number of reoperations is not acceptable. In this specific group however, chances of recurrent instability are extremely high. Patients were only selected for surgery if they had multiple dislocations each month and were functionally impaired. The idea is that treating the young growing patients with a dynamic MPFL reconstruction can also be seen as a temporary stabilization of the joint. If after some time when growth has (almost) ceased and the patella experiences maltracking again, a second definite surgery can be performed addressing all bony abnormalities. Furthermore, operating on children means that if the surgeon manages to find the perfect femoral fixation point while performing a static MPFL reconstruction, this specific point can be completely different after some years of growth.
Although it is only a small group of patients, the results are promising because using the dynamic MPFL technique no bone fixation points are necessary on the femur which could cause growth disturbance. This technique could be a good alternative in patellar stabilizing operations in this specific group. Other options are more invasive and probably have higher complication risk.

Based on our clinical experience and this thesis we believe that the dynamic MPFL reconstruction procedure is more forgiving and less expensive than the static variant but it is still very demanding surgery because of the earlier described pitfalls. Therefore, only experienced surgeons should perform these specific operations.

TIBIAL TUBERCLE OSTEOTOMY (TTO)

Despite the gained popularity and the strong increase in experience in reconstructing the MPFL, not every instable patella can be stabilized using this technique. It remains important to consider the biomechanical factors that made the patella dislocate in the first place. This is never the MPFL, but in almost all cases trochlear dysplasia is the reason for the patella being more prone to dislocate. In addition, the majority of patients have a high or lateral insertion of the patellar tendon on the tibial tubercle. In case of a patella alta, the pathological anatomy with late catching of the patella in the trochlea causes patellofemoral instability and dislocations. As a result, the medial soft tissues will be damaged. As described earlier, the MPFL is unable to withstand the high forces during luxation and is therefore likely to sustain substantial damage as a consequence of luxation. Reconstructing the MPFL does not provide a solution for the initial problem and is therefore most likely to be an insufficient treatment. Nevertheless, there are surgeons who claim that the complication risk after osseous procedures are so extensive that even in those situations an isolated MPFL reconstruction should be considered. We strongly disagree with this and recommend that the best way to create a biomechanical stable patellofemoral joint is to correct the anatomical abnormality.

A TTO is indicated in case of a patella alta or when the attachment of the ligamentum patellae at the tibial tubercle is located too laterally. Again, multiple surgical techniques are described. In **chapter 7** and **chapter 8** we analyzed the complications following different types of TTO's. The sliding technique has the advantage of self-centering, so there is no need for extensive measuring during surgery and subsequently less chance of overcorrection of the deformity. However, the pitfall with this technique is that if the osteotomy is located superficially, the cortical bone piece will be very thin and therefore subjective to delayed, non-union or fracturing of the tibial tubercle. The V-shaped, complete detaching TTO with a step-cut is less popular amongst surgeons because of its presumed high risk of pseudarthrosis and tibial fractures. Considering the results as presented in this thesis, we conclude that the complication rates of both techniques are comparable to what is known from earlier studies on TTO's.[7] The theoretically higher chance of non-union in case of complete detachment of the tubercle could not be confirmed. Tibial fractures were rare with both techniques. In the detaching osteotomy the distal step-cut is crucial, which should be done with great care to prevent creating a stress riser if this cut - in the tibial shaft - is too deep. When this is done with experience and attention, this is a safe and good technique that can produce precise distalization of the patella in case of a patella alta, with a high intrinsic stability of the osteotomy.

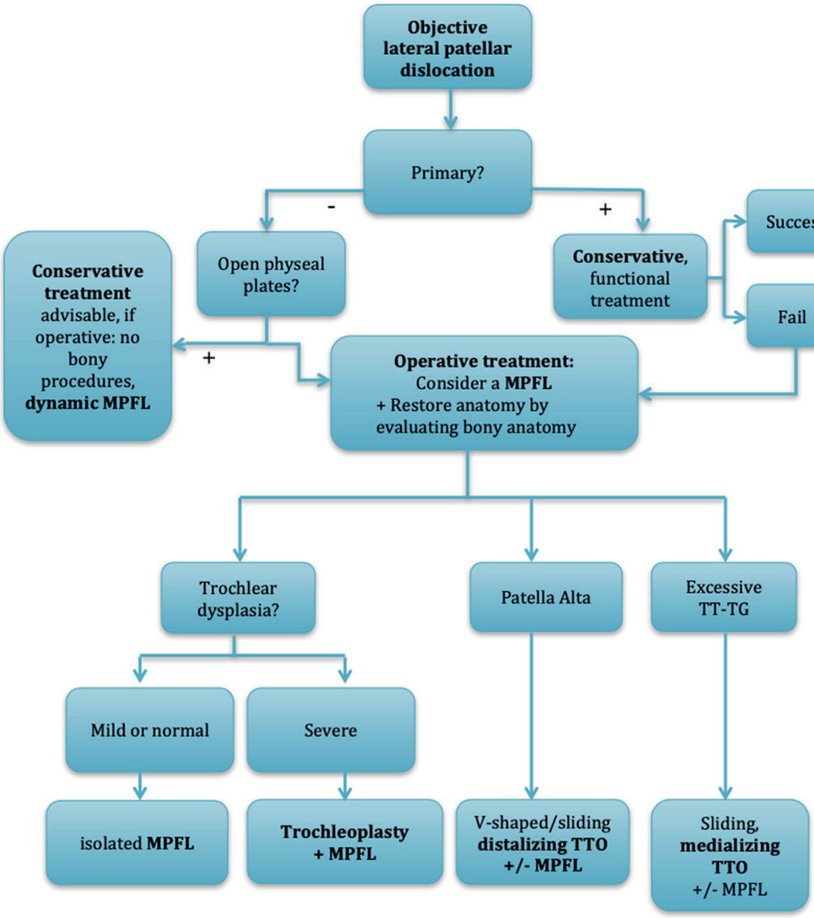
The advantage of the self-centering TTO is the small chance of over-medialization of the TTO. The new position of the tubercle is determined by passively bending the knee while it is held in place with a drill bit to rotate freely. Hence, this is a more functional way of finding the optimal fixation point than relying on the TT-TG. There is some debate about the best measurement for the mediolateral position of the patella. The sliding TTO bypasses this discussion, but it is still unknown whether this "self dictated" position is normal. The V-shaped TTO creates a direct stable situation, where the chances of secondary displacement are very small. Comparing the sliding TTO to the V-shaped TTO, the conclusion is that sliding TTO is best for medialization and the V-shaped osteotomy can be used for distalization.

In conclusion, treating patellofemoral instability is a challenge. There are numerous different influences on the patellofemoral joint. The main important step in planning best treatment is determination of the anatomic abnormalities. Over the last decade, patellar stabilizing techniques like MPFL reconstructions and tibial tubercle osteotomies have been thoroughly studied and improved. The future perspective on patellofemoral instability research should focus on determination of the correct indication for surgery. Imaging techniques like CT and MRI have provided us with much more information than conventional imaging. The detailed slides in three planes provide possibilities for more extensive measurements of all sorts of angles and ratios, but still no specific cut-off points for normal and abnormal values have been defined. For example, in trochlear dysplasia cases quantification of the TT-TG is difficult. This is due to the fact that if the trochlear groove is shallow, or even convex, multiple points can be pointed out for the "deepest" point of the groove (the "TG"). Therefore we believe that this measurement is not reliable in severe cases of trochlear dysplasia. Some authors suggest that they can find a specific point in the notch of the pathologic trochlea to determine the TG.[2,17] However, the TT-TG is stooled on the deepest point in the trochlear groove where it starts on the proximal side of the femur.[6] When a different point in the notch of the trochlear groove is taken, the reference as to what is normal does not apply. Most patients with patellar instability have a dysplastic trochlea to some extent; therefore new tools or measurements for the mediolateral position of the patella require further research.
An additional reason to develop new measurement methods is because Tanaka et al found that knee flexion angle during imaging is a critical factor when measuring TTTG distance to evaluate patellofemoral instability.[16] The mean TT-TG distance varied by almost 6 mm between 5° and 30° of flexion in patients with symptomatic instability. Changes in TT-TG distance and corresponding patellar position appear to be depending on the tibiofemoral rotation that occurs with knee flexion. Seitlinger et al. suggested that the tibial tubercle–posterior cruciate ligament (TT-PCL) distance, defined as the mediolateral distance between the tibial tubercle midpoint and the medial border of the posterior cruciate ligament, is a reliable alternative for assessing lateralization of the tuberosity.[9] Given the differences in TT-TG distance with knee flexion, limiting the anatomic landmarks to the tibia would eliminate the variable

distances with knee flexion. This method also eliminates the difficulty in finding the trochlear landmark in patients with trochlear dysplasia. Despite the desire for simplicity that is driving the use of the TT-PCL measurement, the current literature remains in favor of TT-TG as a tool for evaluation of patellofemoral instability.[2]

From the discussion as depicted above it is clear that developing a coherent treatment algorithm is quite a challenge. Previous described flaws in literature and knowledge produce uncertainties. For clinical use, however, a flowchart can be extremely helpful. Therefore we attempted to formulate an algorithm based on our clinical experience and the studies described in this thesis. This flow-chart may help to identify the best-customized treatment for a patient with certain pathology, based on the anatomic abnormalities present. Different procedures may be combined: an MPFL reconstruction with a trochlea osteotomy, an MPFL reconstruction with a TTO or in selected cases even an MPFL reconstruction with a trochlea osteotomy and a tibial tubercle distalization.

Figure 1: Treatment Algorithm



In this thesis, we show that the optimal conservative treatment of patellofemoral instability is functional with minimal immobilization of the patella and stimulating early active rehabilitation. General practitioners instead of specialized physicians in the hospital can also treat this group of patients. If conservative treatment fails and/or surgery is necessary to stabilize the patella, both dynamic MPFL reconstructions and TTO's are safe and good options. Benefits of a dynamic MPFL reconstruction compared to the more common static alternatives are: the femoral attachment point is less precise; no hardware is needed and this type of reconstruction can also be performed in the skeletally immature. Comparable intra-articular pressures of the patellofemoral joint are achieved. Looping around the adductor tendon is not crucial for prevention of recurrent dislocations. Tibial tubercle osteotomies are relatively safe in experienced hands. Tibial fractures and pseudo-arthrosis are rare and fear for these complications should not be a threshold for surgeons to perform these procedures. The preferred technique is depending on the goal: medialization, distalization or both. In most cases, when the anatomic abnormality is identified, combined procedures are mandatory. The flow-chart can help finding the best treatment option. However, intra-operative testing for stability can demand an "a la carte" surgery so only experienced surgeons should perform these types of operations.

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CHAPTER 12 | DANKWOORD

Promotoren professor Albert van Kampen en professor Nico Verdonschot. Bedankt voor jullie begeleiding gedurende dit hele promotietraject. De combinatie van jullie twee zorgde voor veel creativiteit, gepassioneerde discussies en ideeën over welke richting we op moesten met dit proefschrift. Geduld is een schone zaak blijkt wel weer! Dank jullie wel.

Copromotoren Dr. Sander Koeter en Dr. Sebastiaan van de Groes.
Beste Sander. Ik was nog een puppy toen jij me slinks in een patella-onderzoekje duwde. “Doe dit nou maar, dan word je daarna orthopeed en dat is precies iets voor jou”. Je bleek totaal gelijk te hebben en ik realiseer me maar al te goed, dat ik naast de afronding van dit proefschrift ook mijn opleidingsplek bij orthopedie voor een groot deel aan jou te danken heb. Dank je wel voor alles.

Beste Sebastiaan. Onze samenwerking begon dat ik jou als coassistent op de SEH superviseerde, en nu jaren later ben jij mijn copromotor. Hoe bijzonder is dat! Dank voor de peptalks als ik weer eens kwam klagen over de voortgang van mijn promotie. Er zijn weinig mensen die zo kort na het afronden van hun opleiding door hun oude mede-AIOS voor volwaardig staflid worden aangezien, maar dat is jou met glans gelukt. Dank voor de afgelopen jaren.

Gerjon Hannink,
Beste Gerjon. Mijn rots in de branding op het gebied van statistiek en het goed schrijven van een wetenschappelijk artikel. Fijn dat jij er was om de algehele kwaliteit van dit boekje naar een hoger niveau te tillen. Ik gun elke promovendi een beetje Gerjon om de moed erin te houden. Heel erg bedankt voor al je input.

Jordy van Sambeeck, Siebren Tigchelaar, Loes Schiphouwer, Karlijn Groenen, Anke Lenting, Geerte Olthuis, William van der Stappen, Joris Ploegmakers, Harm Boons.
Beste medeauteurs van dit proefschrift. Zonder jullie was dit boekje er sowieso niet gekomen. Dank jullie wel voor alles.

Willem en Dennis van het ORL, Bram Nijsse. Tijdens de lange sessies in het lab voor de kadaverstudie hebben jullie mij allemaal bijgestaan. Nooit zeuren, altijd met een lach. Dank mannen.

Dr. Job van Susante, Dr. Willard Rijnberg, Dr. Vincent Busch, Dr. Wymenga, Dr. Maarten de Waal Malefijt, Dr. Van de Geest. Beste opleiders, dank voor de stimulering zo nu en dan om door te pakken en de promotie tot een goed einde te brengen.

Dr. Wim Rijnen, beste Wim. Het juiste zetje op precies het goed moment. Hoewel toen oprecht verbolgen, ben ik nu alleen maar blij. Dank!

Mijn paranimfen, Katrijn Smulders en Floortje Verspoor,
Lieve Katrijn. Ik denk dat het best uniek is dat wij, naast dat we keihard samen kunnen lachen en hockeyen, bij vlagen ook op serieus vlak goed matchen. Daarnaast zijn we natuurlijk ongeëvenaard als komisch duo. Heel erg bedankt voor al je hulp en je heerlijke humor de afgelopen jaren.

Lieve Floor. Je bent een van de briljantste mensen die ik de afgelopen jaren heb ontmoet. Heerlijk hoe je zo authentiek, ontwapenend maar ook recht door zee tegelijk kan zijn. Orthopedie krijgt kleur door mensen zoals jij! Jij hebt me zien ploeteren met deze promotie, maar hebt me ook laten zien dat het afmaken echt wel de moeite waard is. Je bent voorlopig nog niet van me af, Amsterdam here we come!

Collega AIOS/ANIOS van de regio orthopedie oost, dank voor de mooie jaren en alle support rondom deze promotie.

Vrienden en vriendinnen, pas op! Met alle vrije tijd in het verschiet kom ik jullie stalken. Dank jullie wel voor de alle support!

Resie Kramer, Vivian en Pieter Aalbers en Jeroen Heijnen.
Lieve schoonfamilie, dank jullie wel voor alle steun en liefde de afgelopen jaren.

Annemiek Monhemius,
Lieve Annemiek, dank je voor jouw taalkundige correcties van dit proefschrift.

Ingrid Rood,
Bedankt voor de moeite die jij in dit proefschrift en in míj hebt gestopt. Waar blijf je zonder goede basis in het leven? Je bent fantastisch en mijn grote voorbeeld. Dank je lieve mam!

Joop Rood,
Ondanks dat je er helaas niet meer bent om dit live mee te maken, heb ik zoveel gehad aan alles wat je me geleerd hebt. Je was een briljante vader, ik mis je nog elke dag.

Gijs en Mijntje Rood, Bob en Huiam,
Een beter gezin had ik me niet kunnen wensen. Thanks voor alle support!

Guido Heijnen,
Lieve Guido, gelukkig schijn je niet erg veel last gehad van deze voortslepende promotie. Dank voor alles wat je doet zodat ik me vaak zo zorgeloos kan storten op mijn werk en onderzoek. En dat je nooit zeurt als ik weer eens veel te laat thuiskom. Het leven is prachtig samen, ik blijf altijd bij jou.

Pim en Suus Heijnen,
Mijn twee briljante kinderen. Werk is leuk, maar jullie maken het leven nou echt mooi. Ik ben zo trots als een pauw!

CHAPTER 13 | CURRICULUM VITAE

Akkie Rood was born on January 10th 1982 in Eindhoven, the Netherlands, named Anneke Rood. In her early childhood her name changed to Akkie because there was a second Anneke in day care. Until this day, this never changed. She grew up in a village called Best with her younger sister and older brother. Most of her youth she spent playing field hockey, which she continued while starting medical school at the Radboud University in 2000 in Nijmegen. From 2000-2007 she played in the national competition at the highest level in the Netherlands with NMHC Nijmegen.

In 2007 she received her qualification as medical doctor and started working as a resident on the emergency department in the Canisius Wilhelmina Hospital in Nijmegen. After a short intermezzo in general surgery, she switched to orthopedics and worked in Helmond and the Radboudumc in Nijmegen. From 2012 until 2019, she was trained as an orthopedic resident in the CWZ, Radboudumc, Rijnstate hospital in Arnhem and the Sint Maartenskliniek in Nijmegen.

The last three months of her training she worked with the Neurosurgeons in the Radboudumc because of special interests in pathology of the spine. Since April till the end of 2019 she will work as a spine fellow in the OLVG Amsterdam. She lives in Nijmegen with Guido Heijnen and their 2 children Pim (2012) and Suus (2015).